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TRACKING AND DATA RELAY SATELLITE SYSTEM CONFIGURATION AND TRADEOFF STUDY

Volume 3. TDRSS Configuration and Data Summary

HUGHES

HUGHES AIRCRAFT COMPANY
SPACE AND COMMUNICATIONS GROUP

HUGHES AIRCRAFT COMPANY
SPACE AND COMMUNICATIONS GROUP
El Segundo, California

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16. Abstract

A reference handbook of configuration data and design information is contained herein. It treats the overall system definition, operations and control, and telecommunication service system including link budgets. A brief description of the user transceiver and ground station is presented. A final section includes a summary description of the TDR spacecraft and all the subsystems. The data presented are largely in tabular form for easy reference.

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FOREWORD

The purpose of this volume is to provide a reference handbook of Tracking and Data Relay Satellite System (TDRSS) Part I baseline configuration data and design information. The organization and content of major subsections in this volume is as follows:

- Section 1, System Definition, contains a system block diagram and identifies the system elements.

- Section 2, Operations and Control, contains an orbit insertion profile, a brief description concerning on-orbit control of the spacecraft, including a listing of auxiliary propulsion, and a description of the telecommunications service operation.

- Section 3, Telecommunications Service System, contains a summary of the telecommunications services and link budgets as well as general repeater characteristics. It also contains a brief description of the TDR repeater as well as the user transceiver and ground station design.

- Section 4, TDR Spacecraft Design Description, is comprised of three subsections:

  4.1, Design Characteristics, contains a discussion of TDRS spacecraft design characteristics including an artist's concept of the spacecraft and a spacecraft configuration layout. It also contains a compilation of detailed spacecraft data: summary of salient characteristics, electrical power budgets, a mass summary, and a listing of spacecraft hardware by subsystem.

  4.2, Interfaces, describes internal and external spacecraft interfaces, including a functional block diagram.

  4.3, Subsystem Description, contains a summary of pertinent data on the spacecraft subsystems, namely, subsystem block diagrams, requirement tables, and mass summaries, as well as some descriptive material on subsystem design.

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ILLUSTRATIONS

TABLES

1. SYSTEM DEFINITION

The TDRSS concept employs two geostationary satellites to provide relay links for telemetry, tracking and command (TT&C) between multiple low earth-orbiting user satellites and a centrally located ground station, as shown in Figure 1-1, making possible nearly continuous reception of data in real time.

The TDRSS comprises the following major elements:

- GSFC network scheduling and data processing facilities
- TDRS ground station
- TDRS control center
- Two TDR satellites
- User spacecraft equipment

The communication links from the ground station to the user are defined as forward links, and the links from the user spacecraft to the ground station are defined as return links.

The forward links contain user command, tracking signals, and voice transmissions, whereas the return links contain the user telemetry, return tracking signal, and voice.

The users are categorized as low data rate (LDR), medium data rate (MDR), and high data rate (HDR) according to their telemetry rates.

2. OPERATIONS AND CONTROL

The TDRSS operations and control involve three major functions:

- TDRS launch and orbital deployment
- TDRS on-orbit control
- TDRSS telecommunication service operations

Each of these topics will be discussed briefly in the following subsections.

2.1 TDRS ORBIT INSERTION PROFILE

The TDRS launch and orbit insertion sequence is similar to that used for other synchronous satellites, e.g., Intelsat IV. The key events in the mission are shown in Figure 2-1.

The final orbit is geostationary with a 7-degree inclination.

2.2 TDRS ON-ORBIT CONTROL

There are two systems for TDRS telemetry and command — K band and VHF. The K band system is prime with the VHF system, which employs an omni antenna on the TDRS, for backup.

TDRS tracking is accomplished using the LDR forward link. A signal is continuously sent to each TDRS on this link via the K band system. Each TDRS repeats the signal at UHF via the broad coverage antenna. A relatively low gain UHF antenna can be used to receive these signals at the ground station, where they are processed to provide range and range rate measurements for the TDRS. The UHF antenna at the ground station is included in the K band antenna.

The on-orbit control operations for the TDRS are:

- East-west stationkeeping
- Attitude maneuvers

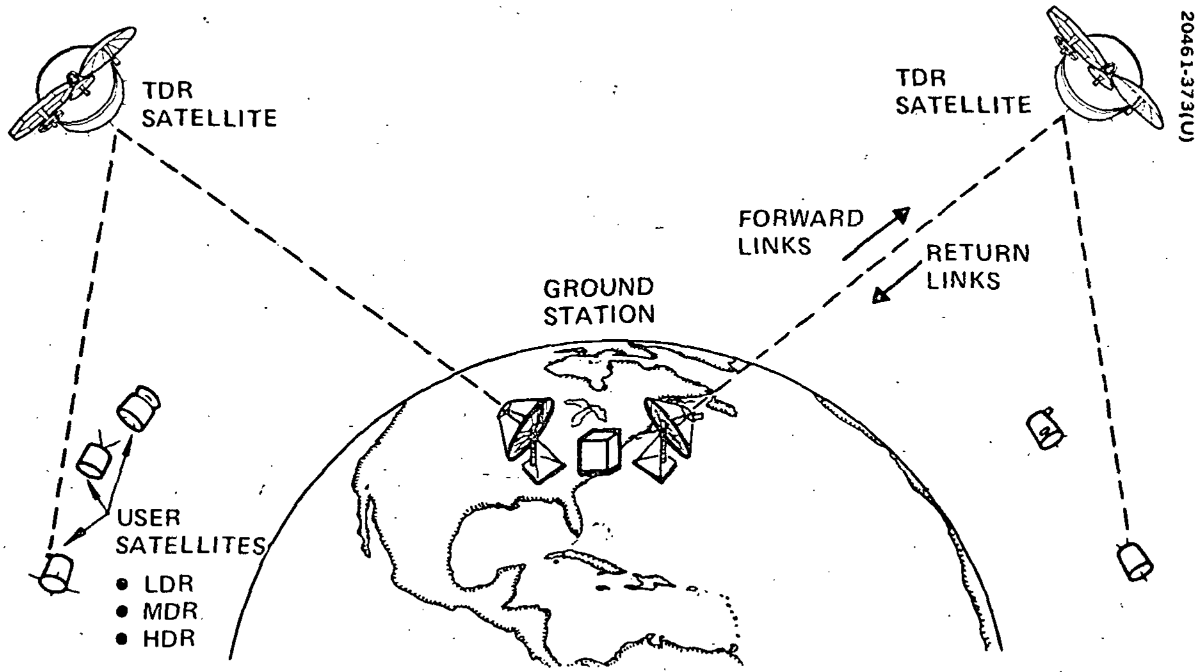

Figure 1-1. TDRSS Concept

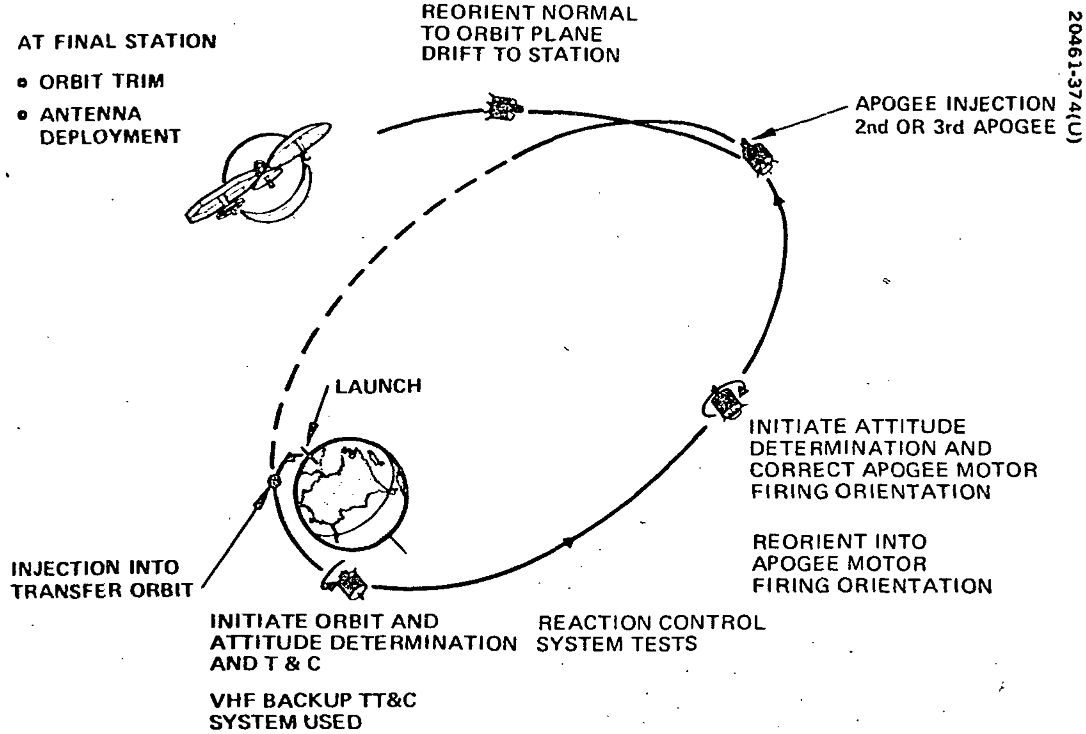

Figure 2-1. TDRS Orbit Insertion Profile

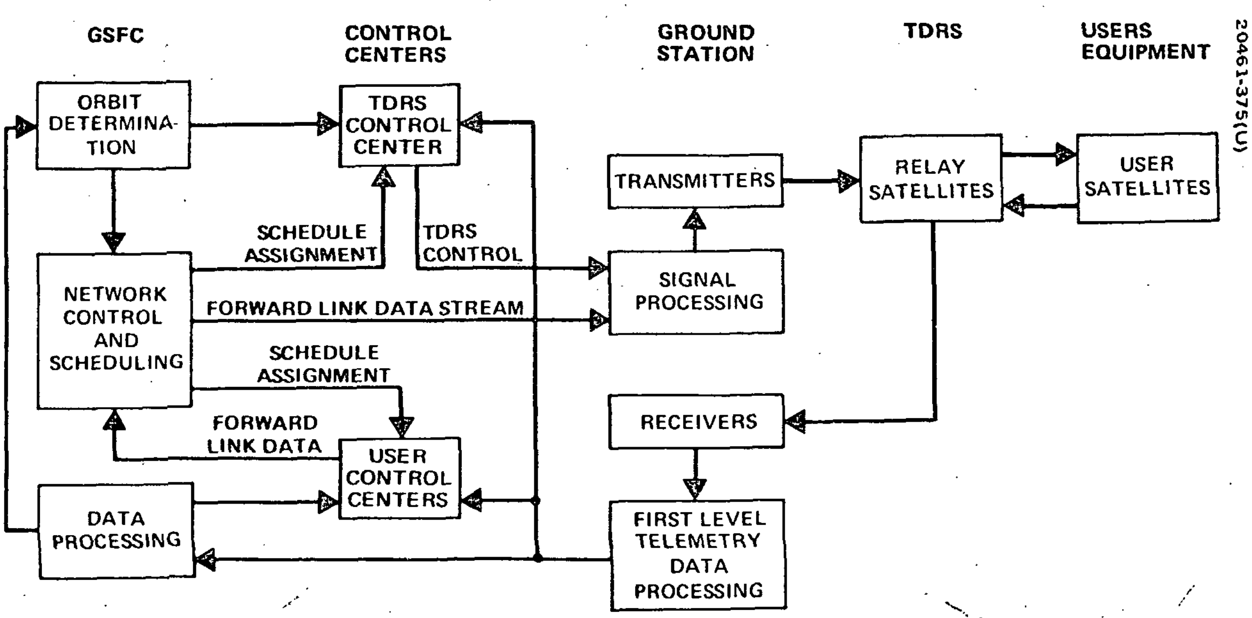

Figure 2-2. TDRSS Functional Operations

- S band and K band antenna pointing
- TDRS repeater channel settings for MDR users

The frequency of east-west stationkeeping maneuvers is approximately one maneuver every 100 days and the frequency of the attitude maneuvers is one maneuver every 2 days. The satellite has sufficient angular momentum so that antenna pointing will not require any attitude correction maneuvers. The stationkeeping and attitude correction maneuvers do not require an interruption of the telecommunication service to the users. A summary of the requirements imposed on the auxiliary propulsion is shown in Table 2-1.

2.3 TDRSS TELECOMMUNICATIONS SERVICE OPERATIONS

The major TDRSS operational elements are shown in Figure 2-2. The operations at GSFC utilize existing equipment and operational procedures for network control, scheduling, and data processing. The control centers will perform only those functions required to control and command the TDR spacecraft (TDRS repeater channel settings, S and K band antenna pointing, attitude maneuvers, and east-west stationkeeping). The ground station houses the RF ground equipment to communicate with the TDR spacecraft (described in sub-section 3.4). The spacecraft will be described in Section 4 and the user transceiver in 3.3.

TABLE 2-1. AUXILIARY PROPULSION REQUIREMENTS

ΔV			168.25 m/sec (552 fps)
Cumulative impulse predictability for		$<$ 10 pulses	20 percent
		$>$ 10 pulses	10 percent
Burn time:	Steady state		None
	Pulse	Axial	70,000
		Radial	30,000
Cold starts:	Axial		1250
	Radial		30

3. TELECOMMUNICATIONS SERVICE SYSTEM

The telecommunication service system consists of the communication equipment in the TDRS, user spacecraft, and ground station. The services and their operational aspects have been briefly discussed above and are depicted in Figure 3-1. The frequency plan is shown in Figure 3-2. The telecommunication services provided via each TDRS are summarized below.

3.1 SERVICES AND LINK PARAMETERS

3.1.1 Services

3.1.1.1 Low Data Rate at UHF/VHF

- Command of, tracking of, and telemetry from up to 20 users; command is sequential, tracking and telemetry are simultaneous for all users.
- Two way voice to a manned spacecraft with an omni antenna.
- Command and voice services can be provided simultaneously, but one or the other is limited to 25 percent usage.

3.1.1.2 Medium Data Rate at S band

- 19.2 Kbps delta modulated voice plus 2 Kbps data (this service is restricted to 50 percent usage and corresponds to a high power transmitter mode) or up to 4 Kbps data continuously to a user spacecraft with a 0 dB gain antenna.
- Up to 1 Mbps return data from a user spacecraft.

3.1.1.3 Order Wire at S Band

- An S band antenna has been provided for an order wire service. This is a broad coverage antenna, thus a request can be made by a manned spacecraft with an omni antenna for MDR service, even if the TDRS narrowbeam S band antenna is not pointed at this user. The order wire service channel bandwidth is 1 MHz.

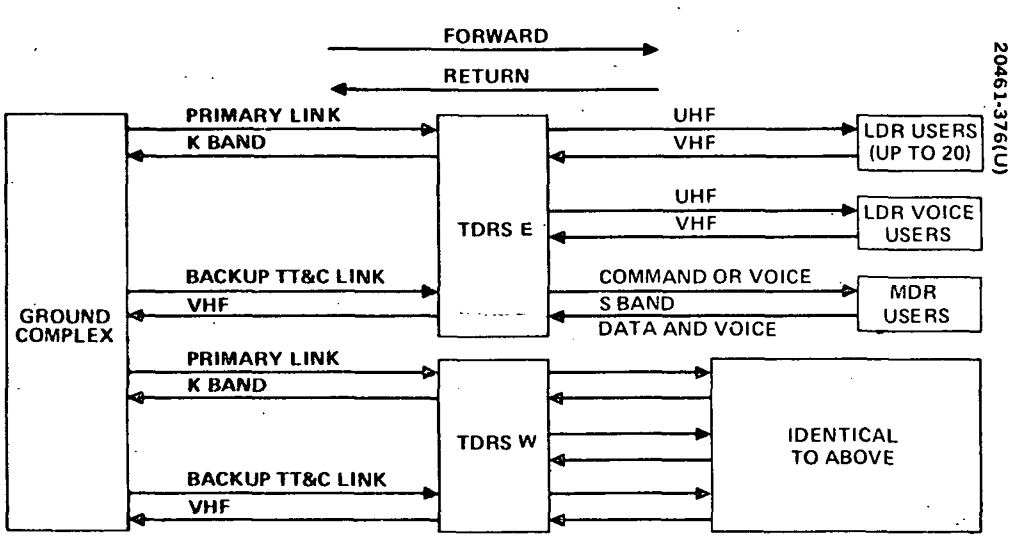

Figure 3-1. Telecommunication Service System

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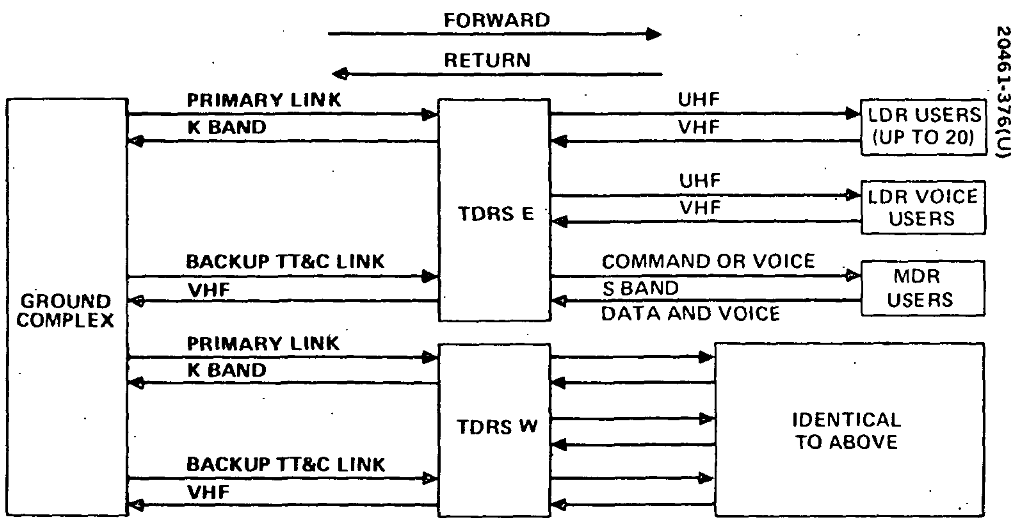
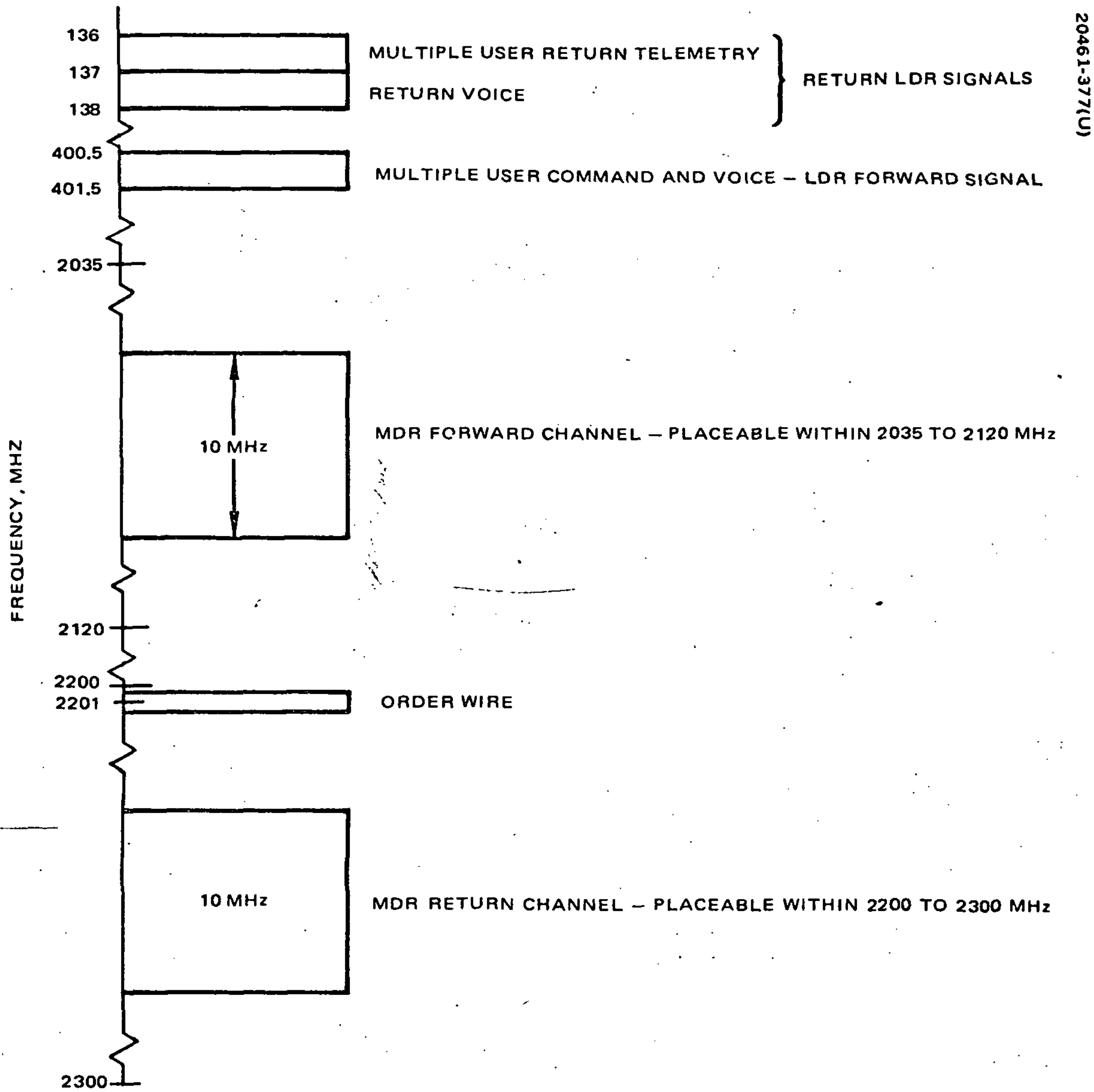
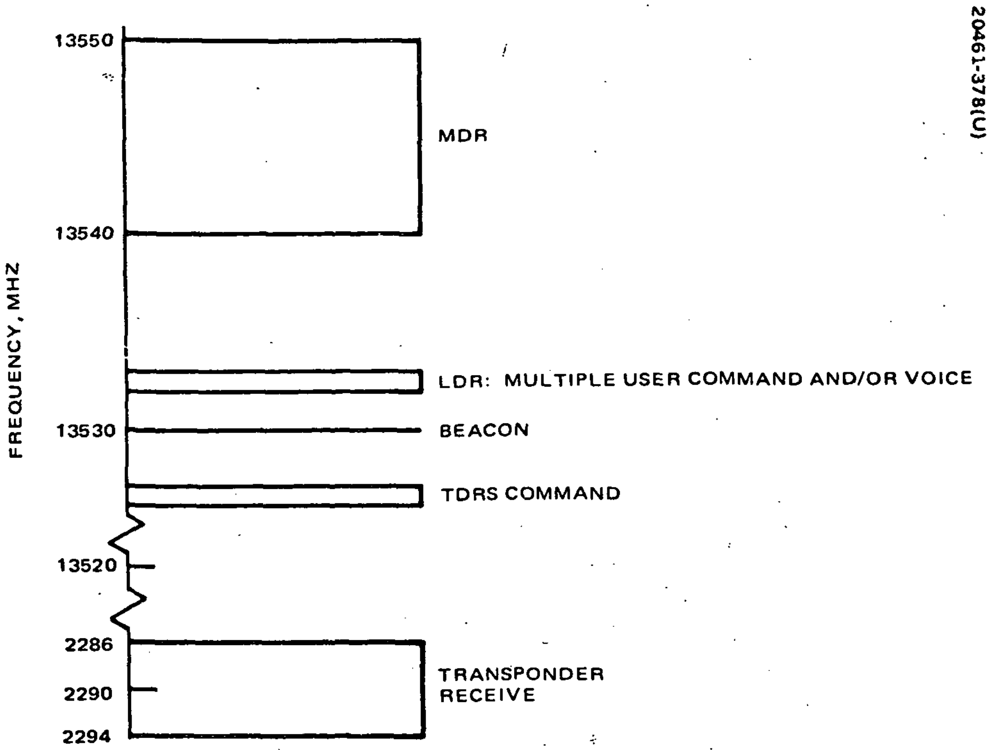


Figure 3-1. Telecommunication Service System

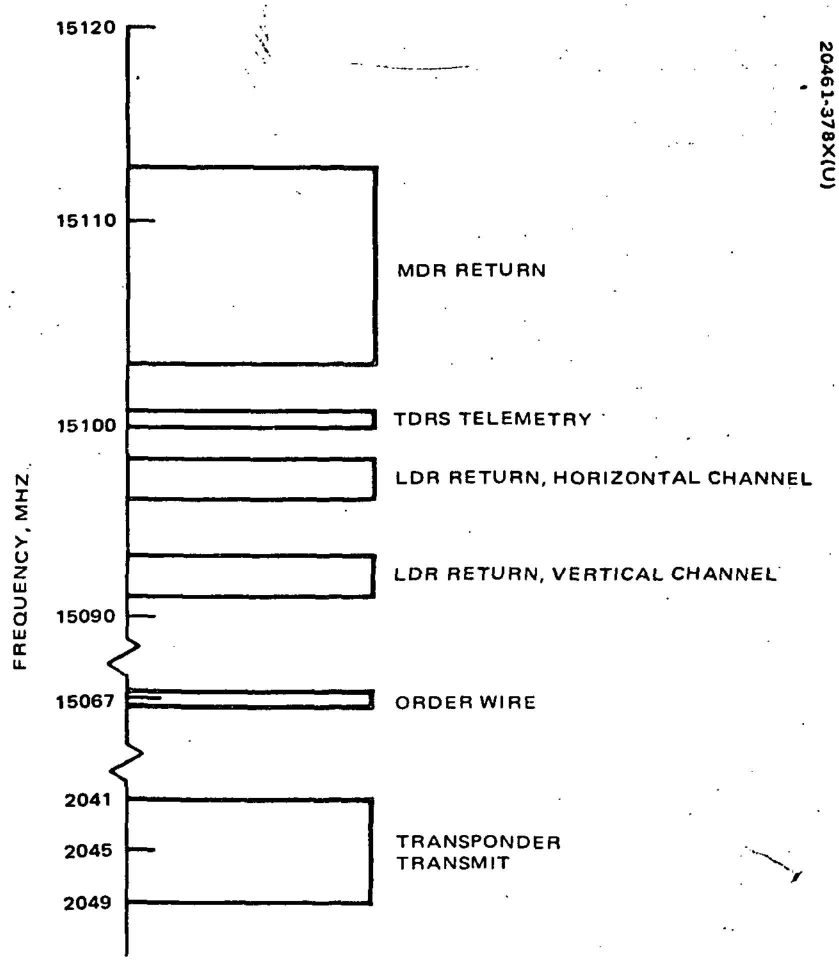


a) TDRS Space Link Spectra

Figure 3-2. Frequency Plane



b) Forward Ground Link Spectra



c) Return Ground Link Spectra

Figure 3-2 (Continued). Frequency Plane

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3.1.1.4 S Band Transponder

- A turnaround S band transponder has been provided to allow accurate TDRS range measurements. The bandwidth is 8 MHz centered at 2290 for receive and 2045 for transmit. The transmitted EIRP is 18 dBw. This transponder will allow trilateration techniques such as those currently being designed for the Synchronous Meteorological Satellite.

3.1.2 Link Parameters

The features, characteristics and parameters associated with each link of each service are presented below.

3.1.2.1 Low Data Rate Service

Forward Link. The user commands and voice signals are multiplexed in synchronous code division using different PN codes, but occupy the same frequency band, which is 400.5 to 401.5 MHz.

Command channel - The user command channel will be time-shared; that is, only one user can be commanded at a time. However, commands may be sent to many users within a period of 1 minute. All users will receive the TDRS transmitted RF signal, thus each command will have a prefix that will activate the command decoder of the intended user.

Other operational features include:

• Automatic user acquisition	User available for command shortly after becoming visible
• Time shared link	Requires synchronized sequencing of user commands
• Fixed timing	User receivers can be standardized Ground operations and equipment can be simplified
• Variable format	Number of bits and their significance in a user command can be different for every user if desired, i.e., command format flexibility
• Baseline bit rate	300 bps
• Probability of bit error	$P_e \leq 10^{-5}$
• PN code length	2048

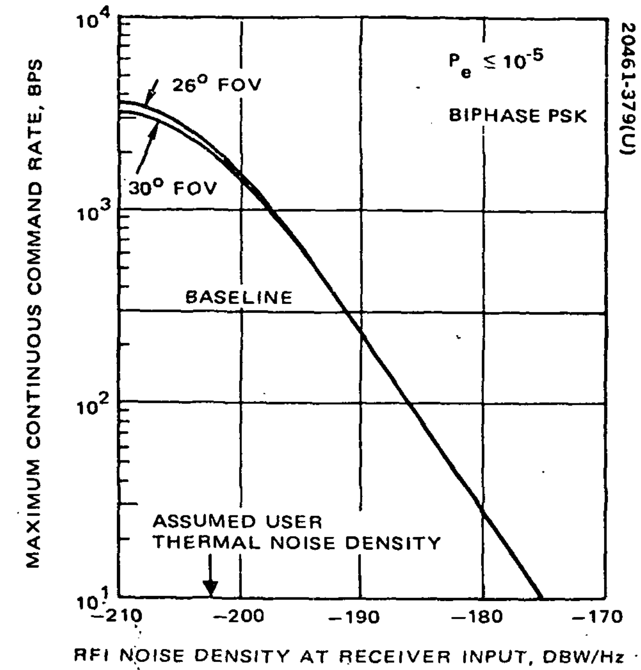


Figure 3-3. Low Data Rate Forward Link Capability

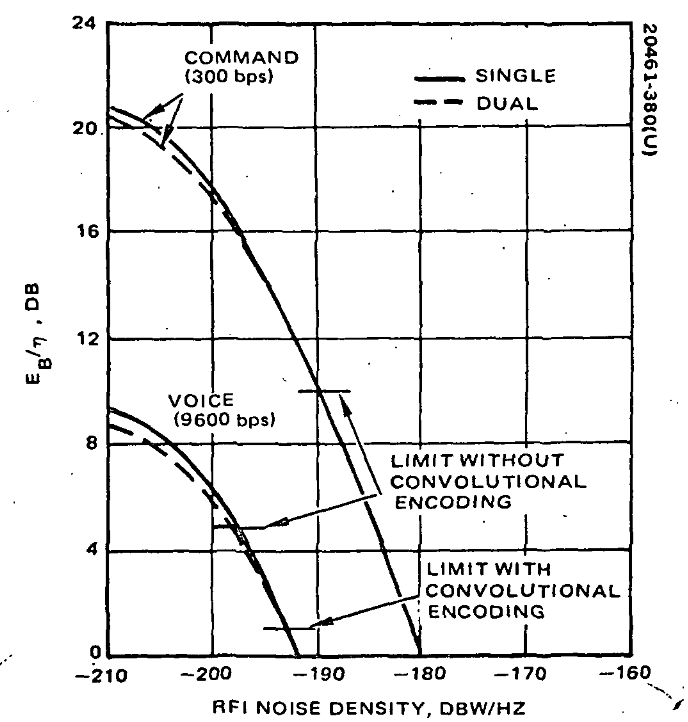


Figure 3-4. UHF Forward Link Signal Concepts

- One code per bit
- Chip rate — 614.4 Kchips/sec
- Biphase PSK IF carrier modulation
- RFI noise density limit — -190 dBW/Hz
- EIRP:

	26 degree Field of View	30 degree Field of View
Antenna gain, dB	12.5	11.8
Radiated power, dBw	17.5	17.5
EIRP, dBw	30	29.3

Analysis of the low data rate links and a study of ground emitters have revealed that RFI is most likely the limiting factor in these links. Figure 3-3 shows how the bit rate is limited by RFI. The parameter chosen to quantify RFI is the average spectral density of the RFI power at the receiver input.

Voice channel -

- Analog-to-digital voice encoding — 9.6 Kbps delta modulation
- Rate one-half convolutional encoding
- PN code length — 32
- One PN code per convolutional code symbol
- Chip rate — 614.4 Kchips/sec
- Biphase PSK IF carrier modulation
- EIRP — Same as command channel

The voice channel employs delta modulation to convert the analog voice signal to a binary wave form. The baseline bit rate is 9.6 Kbps, resulting in high quality transmission. The bit energy-to-noise density is shown in Figure 3-4 as a function of RFI density. It may be noted that the use of convolutional encoding will allow operation at higher levels of RFI and will probably be required.

Return Link. The user telemetry and voice channels occupy separate frequency bands:

Telemetry	136 to 137 MHz
Voice	137 to 138 MHz

User telemetry - Up to 20 users may simultaneously return telemetry. Code Division Multiplexing (CDM) will be used to allow simultaneous telemetry return. The PN codes for CDM will be different for each user spacecraft's telemetry.

Convolutional encoding will be employed on user telemetry for bit error correction; link quality is improved significantly with this technique.

Baseline signal design - The baseline approach assumes that the return bit rate is standardized for all users but this is not a system requirement. With this standardization the baseline parameters are as follows:

- Bit rate — 1200 bps
- P_e — $\leq 10^{-5}$
- Rate one-half convolutional encoding
- One Gold code per convolutional code symbol
- Gold code length — 512
- Chip rate — 1.2288 megachips/sec
- RFI noise density limit for $P_e \leq 10^{-5}$ — -190 dBW/Hz
- Biphase PSK carrier modulation
- User EIRP — $\geq$ 4 dBW
- TDRS G/T (considering receiver generated noise only)

	26 degrees Field of View	30 degrees Field of View
VHF antenna gain, dB	11.8	11.2
Receiver noise figure, dB	3.9	3.9
Receiver noise temperature K	420	420
Equipment G/T (at receiver), dB/K	-14.4	-15.0

The LDR return telemetry channel capacity per user is a function of the number of active users, their EIRP, and the multipath and RFI environment. Figure 3-5 shows the telemetry link capability per user versus the user EIRP, with the RFI noise density as a parameter. The assumptions used to produce this Figure are listed in Table 3-1.

For a user EIRP of 4 dBW, in the absence of RFI, the system is limited to about 2.5 Kbps, as can be seen from the upper curve. With a more advanced user communications terminal with greater EIRP, the link is limited to 4 Kbps.

Voice - The voice signal will be PN code modulated as required to meet CCIR requirements, but not to exceed a 1 MHz bandwidth.

- Analog-to-digital voice encoding — 19.2 Kbps delta modulation
- Rate one-half convolutional encoding
- RFI noise density limit — -180 dBW/Hz
- Biphase PSK carrier modulation

TABLE 3-1. LOW DATA RATE RETURN TELEMETRY CHANNEL ASSUMPTIONS

- 20 visible users
- Average received power of other users 4 dB more than user of interest
- Average relative multipath per user -6 dB
- RFI noise density measured at TDRS receiver input
- TDRS G/T ≥ -16 dB/K (edge of coverage)
- Polarization combining 0.5 dB from theoretical
- PN correlator/convolutional decoder operation 2 dB from theoretical
- Ground link signal-to-noise ratio, ≥ 16.5 dB
- Bit error rate, $\leq 10^{-5}$
- RF bandwidth, 1 MHz

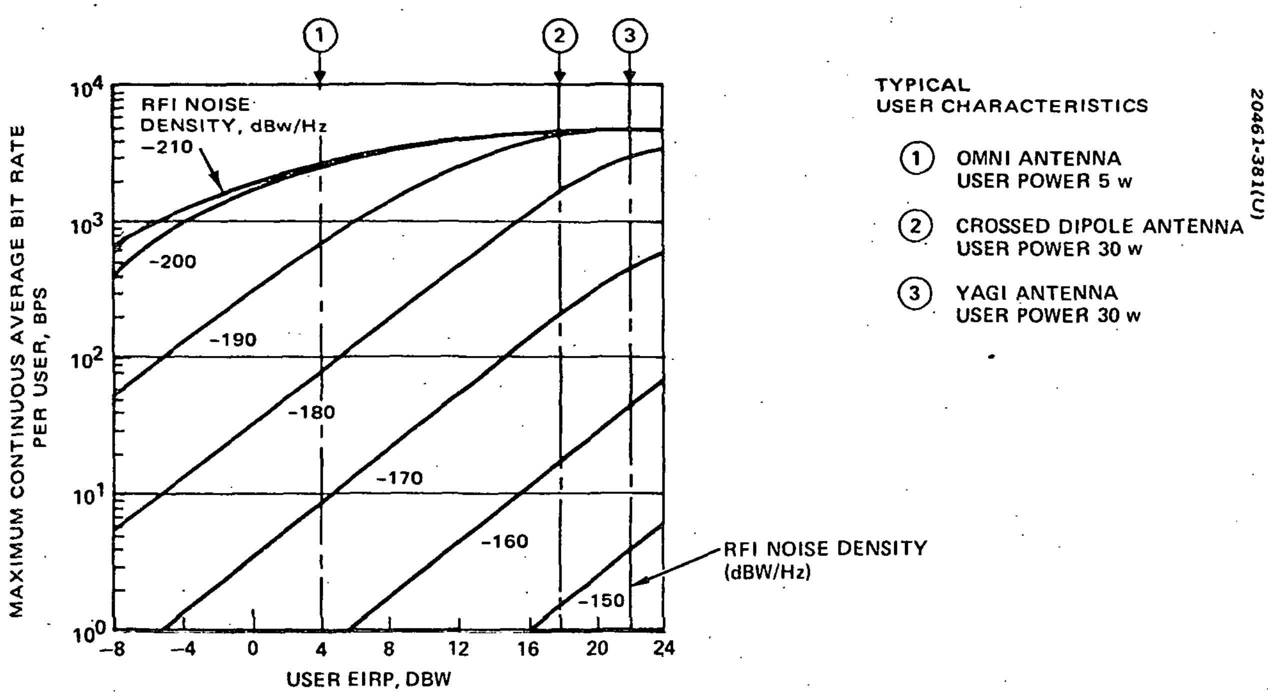


Figure 3-5. Low Data Rate Return Link Capability

The signal spectrum can be located anywhere in 137 to 138 MHz. Minimum RF bandwidth is 60 KHz, but CCIR limits may require spreading. TDRS G/T is the same as for the telemetry channel.

Tracking. Due to the PN code signaling, user spacecraft receivers automatically acquire and synchronize to the signal transmitted from a TDRS. After the brief acquisition period, range and range rate measurements can be made. However, the user's transmitter must be turned on, and the return signal required at the ground station. A particular operational advantage of the signaling concepts used here is that both range and range measurements can be made simultaneous with telemetry reception, and no forward link commands are required.

Range measurement uncertainty is affected by system noise, of which RFI appears to be the most severe. Figure 3-6 shows the RMS uncertainty as a function of RFI noise density for both forward and return levels. The total RMS uncertainty is the sum of the two link contributions.

3.1.2.2 Medium Data Rate Service

The medium data rate service requires a high gain antenna on each TDRS. This antenna has the angular freedom to follow user spacecraft in orbits with altitudes up to 5000 km. Because of the narrowbeam antenna pattern, two way communication is possible with only one user spacecraft at a time via each TDRS.

Forward Link

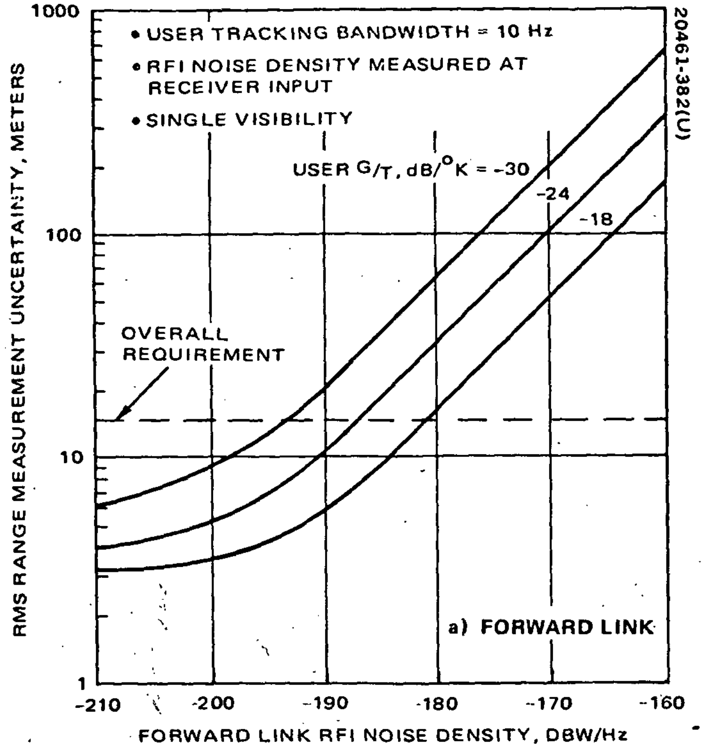
- Channel bandwidth, 10 MHz
- Channel band placeable by ground command anywhere in 2035 to 2120 MHz band with 1 MHz discrete steps
- High power mode

Antenna gain	36 dB
Radiated power	11 dB
EIRP	47 dB

- Low power mode

Antenna gain	36 dB
Radiated power	5 dB
EIRP	41 dB

Figure 3-7 shows the maximum possible data rate for the forward link assuming no error correction encoding and a receiver system noise temperature of 800 K.



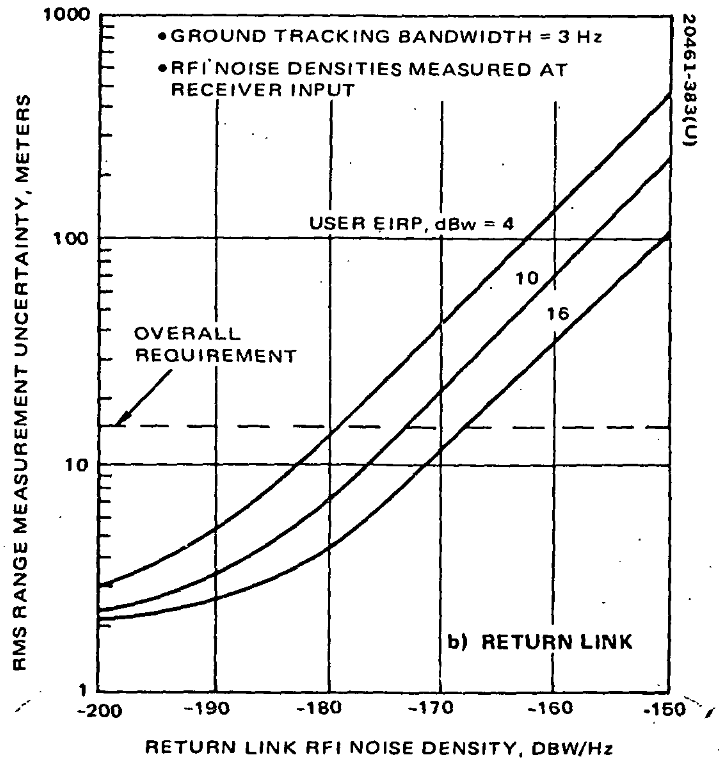
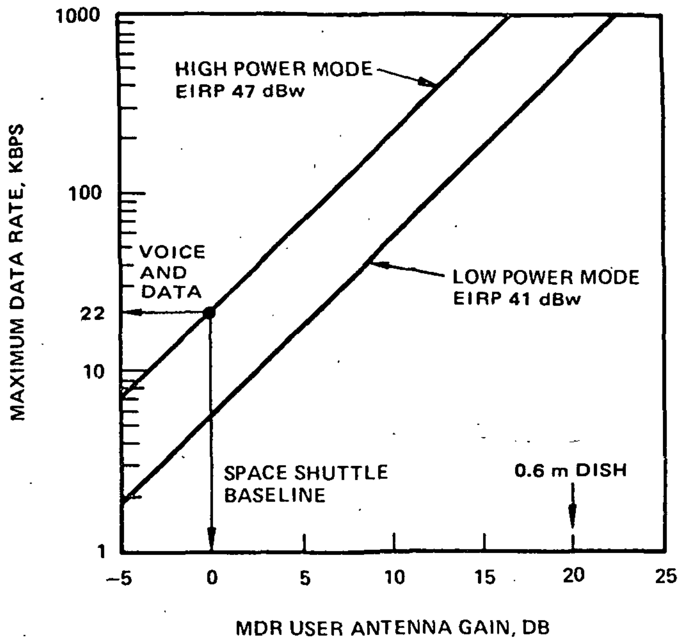


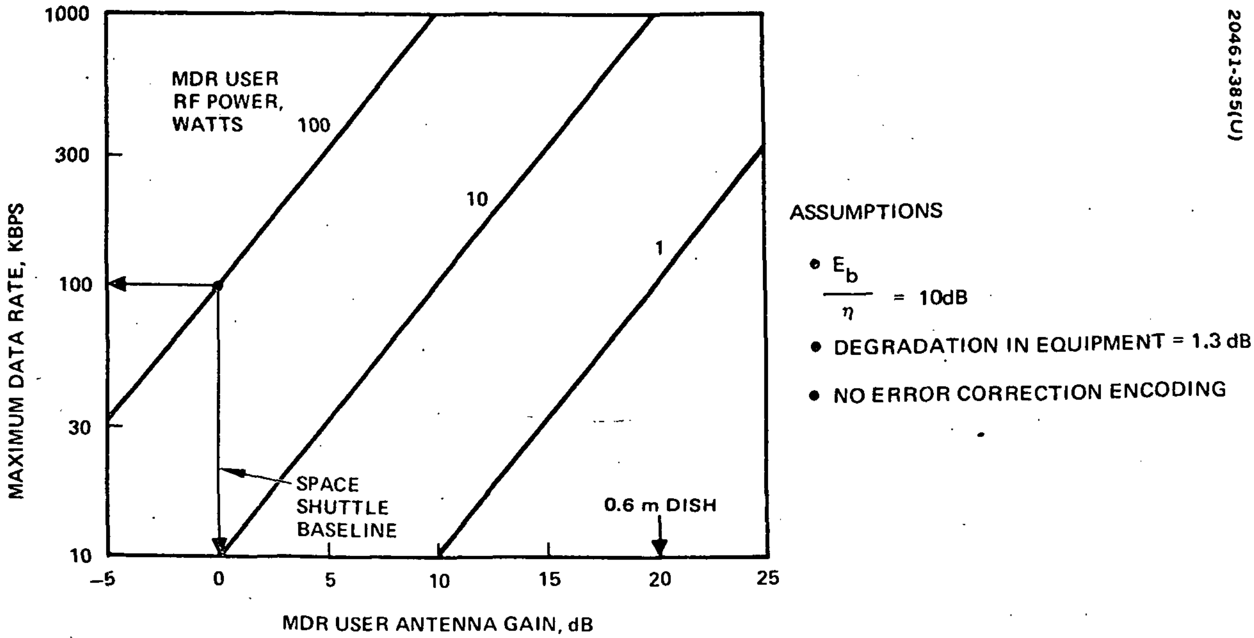
Figure 3-6. RMS Range Measurement Uncertainty



ASSUMPTIONS

0.5 dB USER POINTING AND LINE LOSS
900°K USER SYSTEM NOISE TEMP
$\frac{E_b}{\eta} \geq 10dB$
NO DEGRADATION IN CORRELATION RECEIVER AND DEMODULATOR

Figure 3-7. Medium Data Rate Forward Link Capability



ASSUMPTIONS

- $\frac{E_b}{\eta}$ = 10dB
- DEGRADATION IN EQUIPMENT = 1.3 dB
- NO ERROR CORRECTION ENCODING

Figure 3-8. Medium Data Rate Return Link Capability

Return Link

- Channel bandwidth, 10 MHz
- Channel placeable by ground command anywhere in 2200 to 2300 MHz band with 1 MHz discrete steps G/T = 10.3 dB/K at receiver considering only receiver noise

Figure 3-8 relates the maximum possible data rate to user power and antenna gain assuming no error correction encoding. The use of error correction encoding would increase the maximum data rate of both the forward and return links by a factor of up to 7.

3.1.2.3 Order Wire Service

- Frequency band 2200.5 to 2201.5 MHz (1 MHz)
- G/T ≥ -13 dB/K at receiver over 19.5 degree earth-centered cone considering only receiver noise.

3.1.2.4 S Band Transponder

- Frequency band

  Receive: 2286 – 2294 MHz

  Transmit: 2041 – 2049 MHz
- EIRP

  Antenna gain ≥ 13.0 dB

  Radiated power = 5 dBw

  EIRP ≥ 18.0 dBw

3.1.2.5 Ground Link

Forward Link

- Frequency band: 13526 to 13550 MHz (see Figure 3-26)
- G/T = 14.5 dB/K

  G = 18.5 dB

  T = 2000 K considering only receiver noise (NF ≤ 9 dB)
- Minimum carrier to noise power ratios at TDRS receiver in each channel:

LDR	12 dB
MDR	6 dB
TDRS command	40 dB
Beacon	40 dB

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1.3 dB

ING

Parameter	LDR Command UHF	Voice UHF	MDR Forward S Band		Ground K Band	S Band Transponder
			High Power	Low Power		
TDRS EIRP	-30.0*	30.0	47.0	41.0	EIRP	18.0
TDRS pointing loss	-	-	-0.5	-0.5	-0.5	-
Space loss	-177.5	-177.5	-192.0	-192.0	-208.4	-192.0
Receive antenna gain	-3.0	-1.0	G_u	G_u	63.0	32.0
Receive pointing loss	-	-	-0.3	-0.3	-0.5	-0.3
Receive line loss	-0.5	-1.0	0	0	-0.3	-1.0
Receive ellipticity loss	-3.0	-1.0	0	0	-0.2	-0.2
Receive power, P_r	-154.0	-150.5	G_u-146	G_u-152	EIRP-146.9	-143.5
Receiver noise figure, dB	3.75	3.75	5.5		3.8	3.8
Receiver noise temperature, K	400	400	750		400	400
Background noise temperature, K	50	50	50		20	50
Total system noise temperature, K	450	450	800		420	450
Noise density, η_T dBw/Hz	-202	-202	-199.5		-202.3	-202.0
Pr/η_T dB-Hz	48	51.5	G_u+53.5	G_u+47.5	EIRP+55.4	58.5

*For 26 degree conical coverage, 29.3 dBw for 30 degree coverage.

TABLE 3-3. TDRS RECEIVE LINK BUDGETS

Parameter	LDR VHF (minimum)	Voice VHF	MDR S Band	Order Wire S Band	Ground K Band
Transmit power	7.0	20		20	P
Transmit antenna gain	-3.0	0	EIRP	0	62
Transmit pointing plus line loss	-	-		-	-3
Space loss	-167.5	-167.5	-192.7	-192.7	-207.5
TDRS antenna gain	11.2*	11.8	36.7	13.2	18.5
TDRS pointing loss	-	-	-0.5	-	-2.0
TDRS line loss	-1.0	-1.0	-2.2	-1.0	-1.0
TDRS ellipticity loss	-0.5	-0.2	0	-0.2	0
Receiver power, PR	-153.8	-136.9	EIRP -158.7	-160.7	P-133
Noise figure, dB	3.9	3.9	3.9	3.9	9
Receiver noise temperature, K	420	420	420	420	2000
Earth noise temperature, K	210	210	300	300	300
Total system noise temperature, K	630	630	720	720	2300
Noise density, η_T, dBw/Hz	-200.6	-200.6	-200	-200	-195
P_r/η_T CB-Hz	46.8	63.7	EIRP +41.3	39.3	P + 62

*For 30 degree conical coverage.

3.2 TDRS REPEATER

A functional block diagram of the TDRS repeater is shown in Figure 3-9.

Every active element in the repeater system is completely redundant. The repeater receives four different K band frequency channels from the ground station via two low gain K band horn antennas. These channels are shifted to an intermediate frequency, amplified, and distributed via a power divider.

The output of the six way power divider supplies the UHF transmitter, the S band transmitter, and the command subsystem. One additional signal, the beacon, is received by the K band receiver that phase locks its local oscillator to this reference. The local oscillator signal then drives the frequency synthesizer to provide coherent translation of all frequencies within the communication subsystem.

The signals from the VHF receivers, the S band receivers, and the S band order wire receivers are each shifted to a unique IF frequency before being summed in the 10 way power summer. The output of the power summer is fed into the K band transmitter. Telemetry and command signals are also routed through the K band transmitter.

TDRS antenna parameters are summarized in Table 3-4. Transmitter and receiver parameters have already been tested. Further detail is presented in subsection 4.3.1.

3.3 USER TRANSCEIVER

Both low data rate and medium data rate users will require spread spectrum transceivers. The carrier signals are modulated by binary PN sequences (codes), which in turn have been modulated by data. The use of PN coding for spectrum spreading accomplishes four objectives: 1) it allows code division multiplexing, 2) it reduces multipath interference, 3) it reduces the earth incident flux density (to meet CCIR requirements), and 4) it improves range measurement accuracy. All four of these reasons are important in the LDR system, and all but the first are important in the medium data rate system. The low data rate PN symbol (chip) rate is 614,400 chip/sec in the allocated 1 MHz (400.5 to 401.5 MHz) band. The bandwidth of the medium data rate service is 10 MHz, and the signal must be spread over most or all of this band to minimize the flux density. Thus, the MDR signaling rate may be 10 times greater than that of the LDR system. However, the transceiver operation will be basically the same for both services. The user transceiver (receiving/transmitting equipment) consists of the following major components, interrelated as shown in Figure 3-10: receiver, command data correlator, telemetry modulator, transmitter, interface buffers, and a signal acquisition, matched filter correlator.

For 30 degree conical coverage.

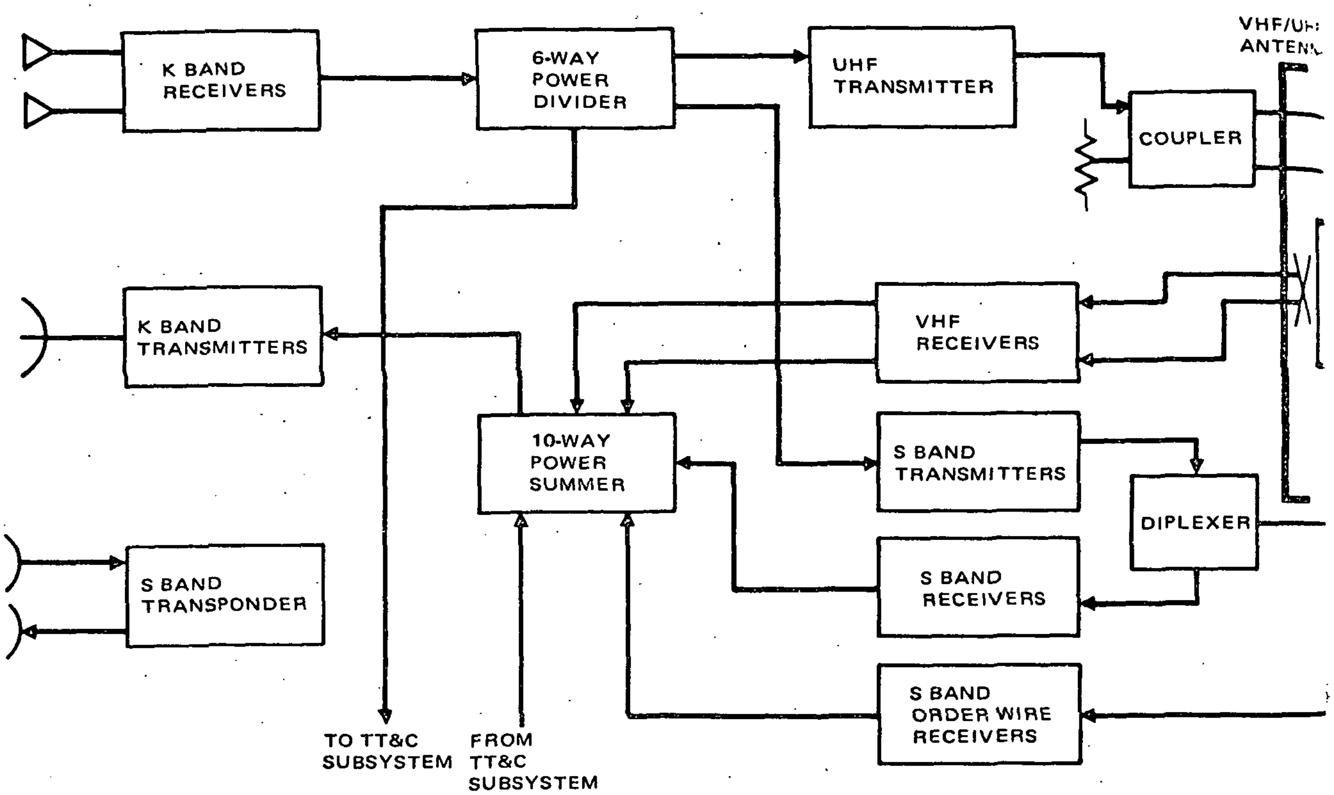


Figure 3-9. TDRS Repeater

TABLE 3-4. TDRS ANTENNA PARAMETERS

Link	Antenna Frequency, MHz	Antenna Diameter, meters	Minimum Antenna Gain, dB
Low data rate forward	UHF	1.43	12.5
Low data rate return	UHF	3.82	11.8
Medium data rate forward	S band	3.82	36.0
Medium data rate return	S band		13.6
Order wire	S band	0.267	13.1
TDRS/ground	K band	1.43	44.0
Ground/TDRS	K band	Horns	18.5

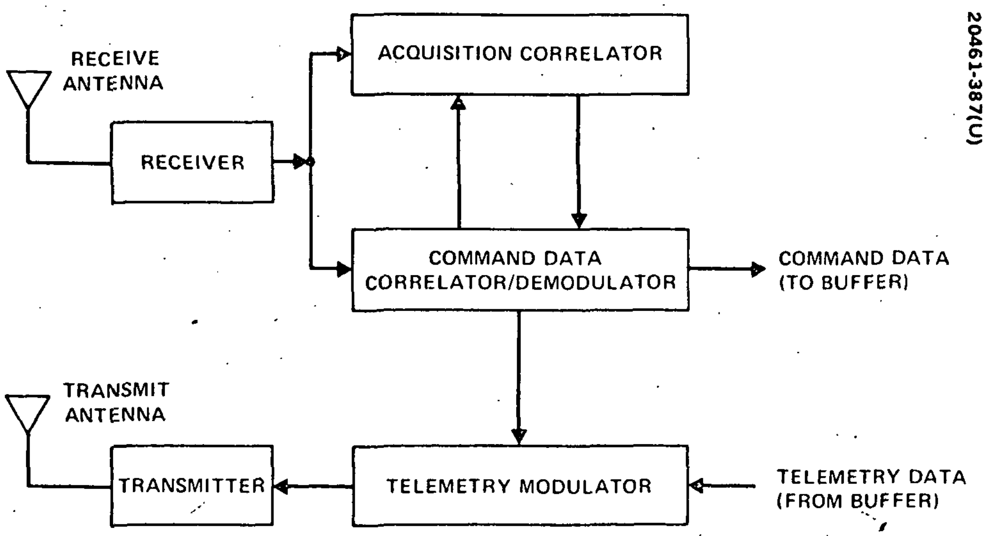


Figure 3-10. User Transceiver

The acquisition correlator permits rapid forward link signal acquisition and provides PN code timing to the command correlator, which maintains pattern and frequency lock after initial acquisition. The telemetry transmitter frequency may be phase locked to the received frequency for ranging, but may also be allowed to run free during telemetry data transmission enabling handover between TDRSs without interrupting data flow.

To operate with the TDRS system, a user spacecraft does not need to replace or modify its NASA ground station-compatible equipment, but must supplement it with the TDRS compatible transceiver and antennas. Two types of standard transceivers are envisioned, one for LDR users and one for MDR users. These transceivers can be connected with a switch to the regular command decoder and telemetry encoder. The choice between the ground station or TDRSS operation could be made any time during the user's mission by a simple command of the switch setting. If the data and command rates for both modes of operation are different, an interface buffer unit will also be required as part of the transceiver package.

In addition to the standard transceiver, the LDR users will probably require a UHF antenna. The VHF link to the TDRSs is compatible in frequency with the user to ground station link.

Figure 3-11 presents a more detailed transceiver description with numerical values corresponding to the baseline parameters of LDR forward command and return telemetry links.

For this implementation, the acquisition correlator gives the following performance when the bit energy-to-noise density, E_b/η at the receiver is 0 dB, which is 10 dB below the link design value:

Mean time to threshold (synchronous signal output)	0.1 second
Probability of correct acquisition	0.99
Probability of a false synchronization output	0.01

Preliminary estimates of the physical parameters are shown in Table 3-5.

3.4 GROUND STATION DESIGN

The ground station is the interface element between the TDRS and the two control centers - GSFC and the TDRS control center. The general relationship of the ground station to the other elements is shown in Figure 3-12. Also shown in the figure are three major portions of the basic ground station: 1) a terminal for maintaining RF communication with TDRS east, 2) a terminal for maintaining RF communication with TDRS west, and 3) a common area containing demodulation and processing equipment, which will be applied to signals from both terminals.

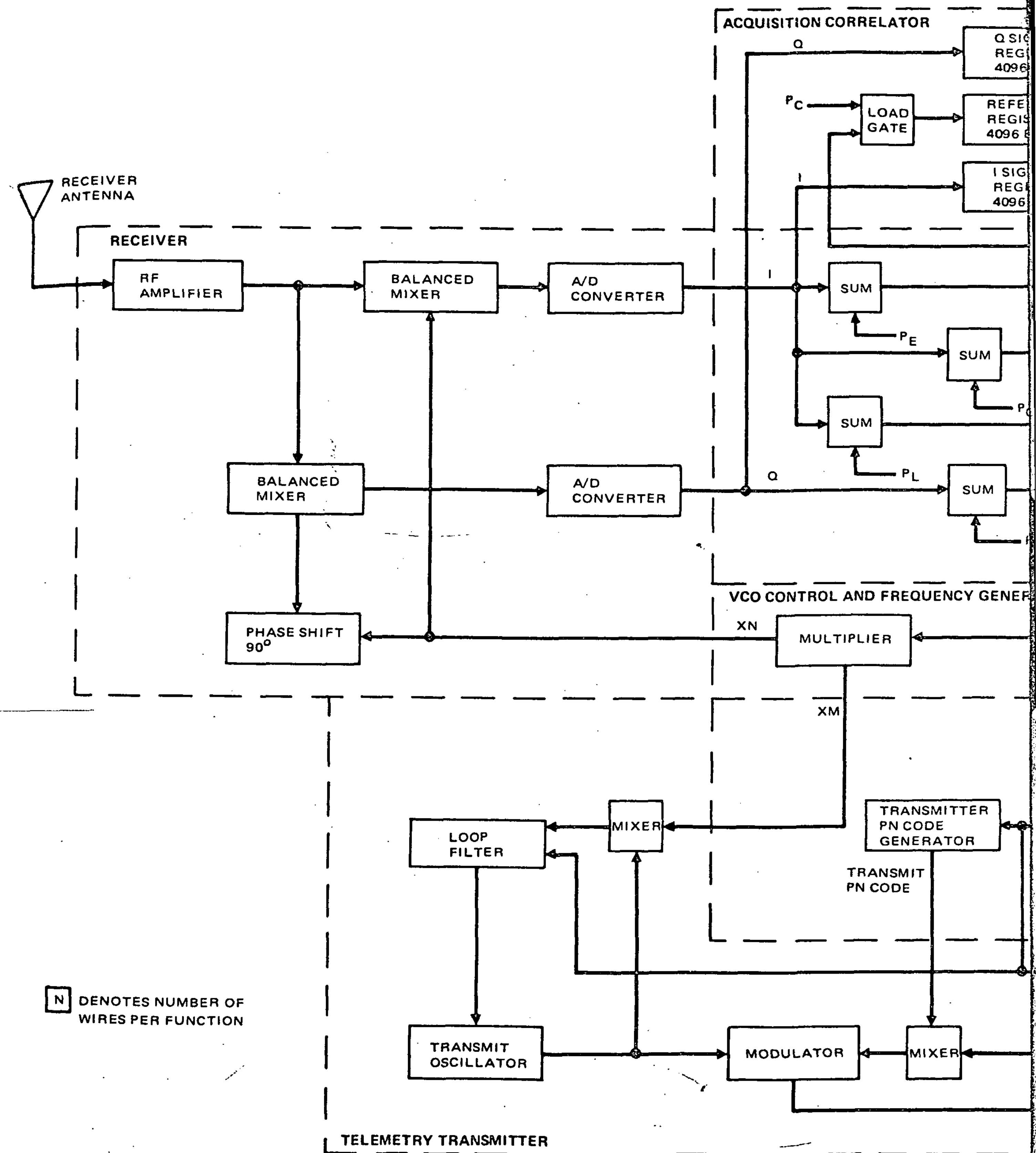
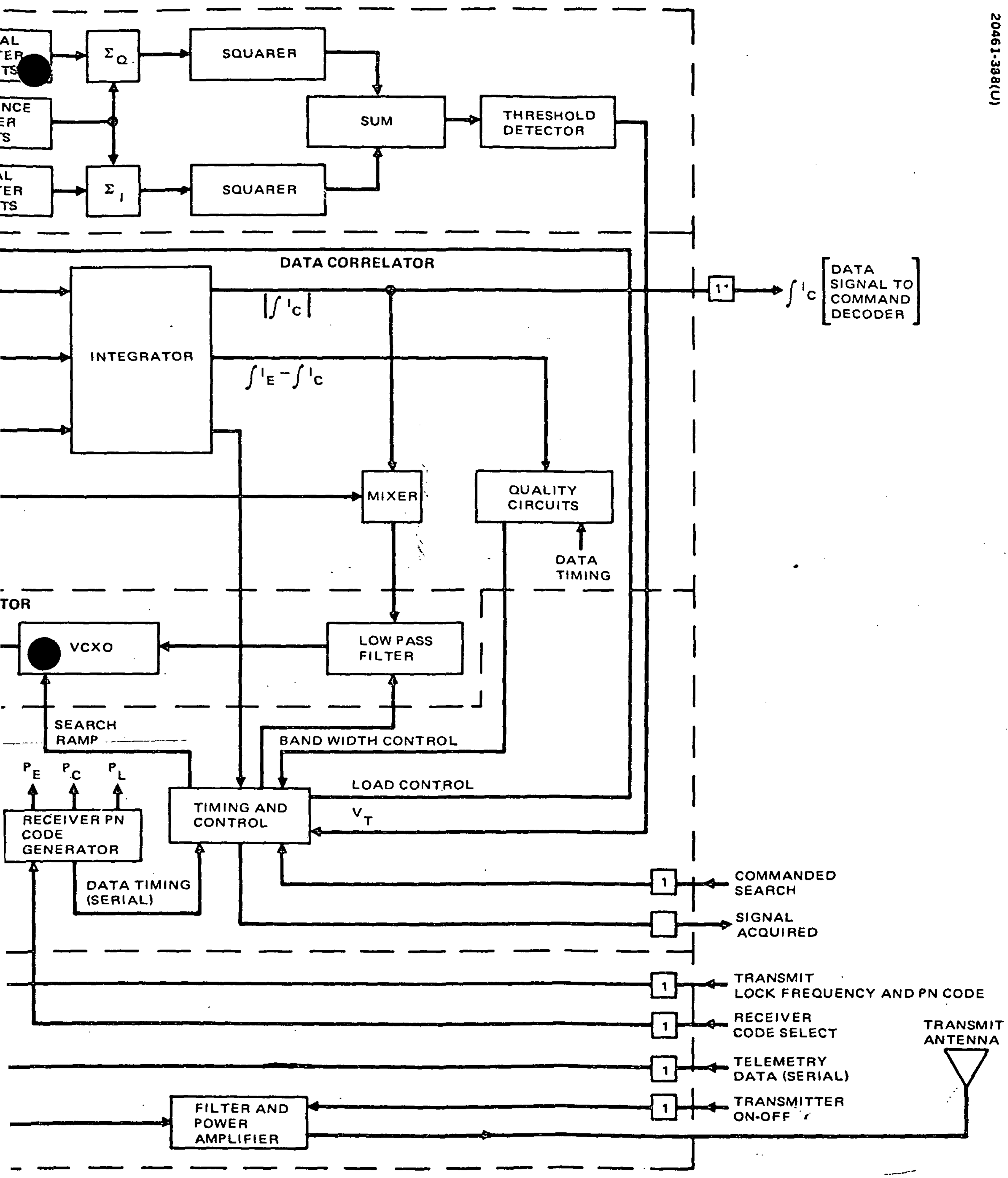


Figure 3-11. User Equipment Transceiver


SQUARER
SUM
THRESHOLD DETECTOR
SQUARER
DATA CORRELATOR
INTEGRATOR
DATA SIGNAL TO COMMAND DECODER
MIXER
QUALITY CIRCUITS
DATA TIMING
TOR
VCXO
LOW PASS FILTER
SEARCH RAMP
BAND WIDTH CONTROL
LOAD CONTROL
TIMING AND CONTROL
RECEIVER PN CODE GENERATOR
DATA TIMING (SERIAL)
COMMANDED SEARCH
SIGNAL ACQUIRED
TRANSMIT LOCK FREQUENCY AND PN CODE
RECEIVER CODE SELECT
TRANSMIT ANTENNA
TELEMETRY DATA (SERIAL)
TRANSMITTER ON-OFF
FILTER AND POWER AMPLIFIER

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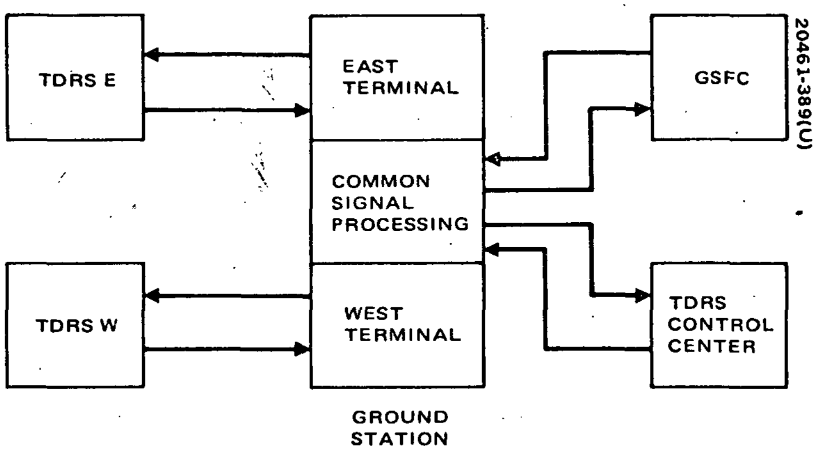


Figure 3-12. Overall Ground Station Concept and External Interfaces

TABLE 3-5. USER TRANSCEIVER EQUIPMENT

Item	Number	Mass, kg	Power, watts
LDR User			
Command receiver	2	2.0	1
Telemetry transmitter	2	4.0	20
Frequency synthesizer	2	2.0	1
Signal processor	2	1.0	3
Antennas	1 Set	2.0	-
Total		11.0	25
MDR User			
Command receiver	2	1.4	1
Telemetry transmitter	2	3.4	20
Frequency synthesizer	2	2.0	1
Signal processor	2	1.0	3
Antenna	1	1.4	-
Gimbal		4.2	-
Gimbal driver	2	1.8	6
Total		15.2	31

The RF terminals are of conventional design, but the signal demodulation and processing equipment, although not new in concept, has not been previously applied in the complexity required for simultaneous multiple user communication via the TDRSS.

It should be mentioned that a third terminal may be required for communication with the in-orbit spare TDRS and for redundancy. This will require only a slight increase in the processing equipment and its configuration controls.

The terminals consist of five major portions: 1) the antenna structure, 2) the antenna tracking subsystem, 3) the K band RF/IF subsystem, 4) the VHF backup system, and 5) the UHF antenna for TDRS tracking. The signal processing can be functionally separated into six portions:

1) LDR user telemetry demodulation

2) LDR voice demodulation

3) MDR user telemetry demodulation

4) LDR forward link modulation

5) MDR forward link modulation

6) TDRS telemetry, tracking, and command

7) User range and range rate measurements

3.4.1 Ground Terminal Design

The equipment and associated parameters for a terminal are listed below:

Antennas

- K band/VHF antenna
  1) Reflector diameter, 12.8 meter (42 feet).
  2) K band cassegrain feed
  3) VHF near-focus feed
  4) Polarization
     a) K band, circular, C/CC
     b) VHF linear V/H
  5) Gain
     a) 13.5 GHz, 62 dB
     b) 15.0 GHz, 63 dB
     c) VHF, 21.5 dB
  6) Pedestal type: AZ/EL
  7) Autotrack system: single RF channel amplitude comparison, monopulse type
- UHF antenna for TDRS tracking
  1) Frequency, 400.5 to 401.5 MHz
  2) Gain, 5 dB

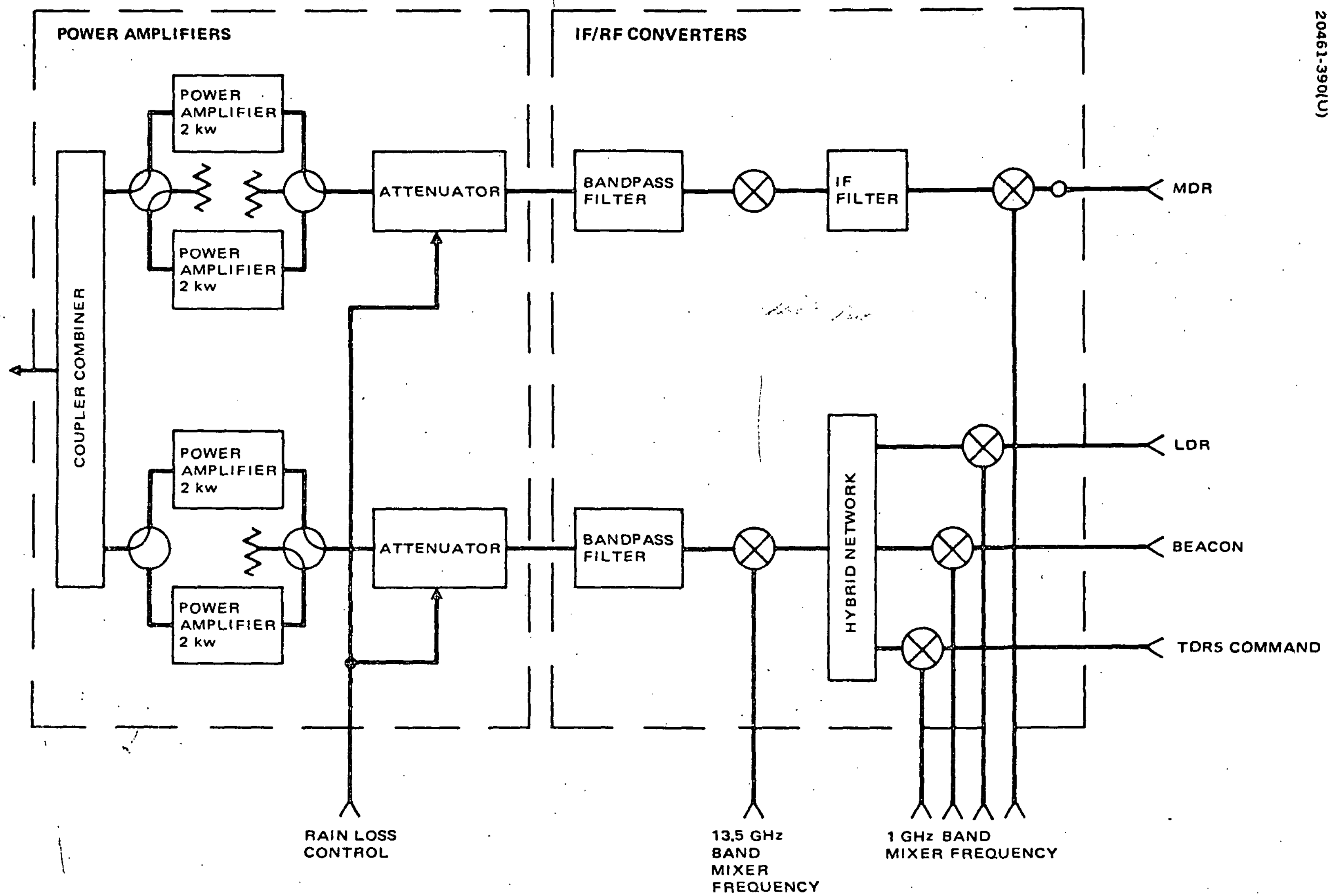


Figure 3-13. Configuration C, Power Amplifier and IF/RF

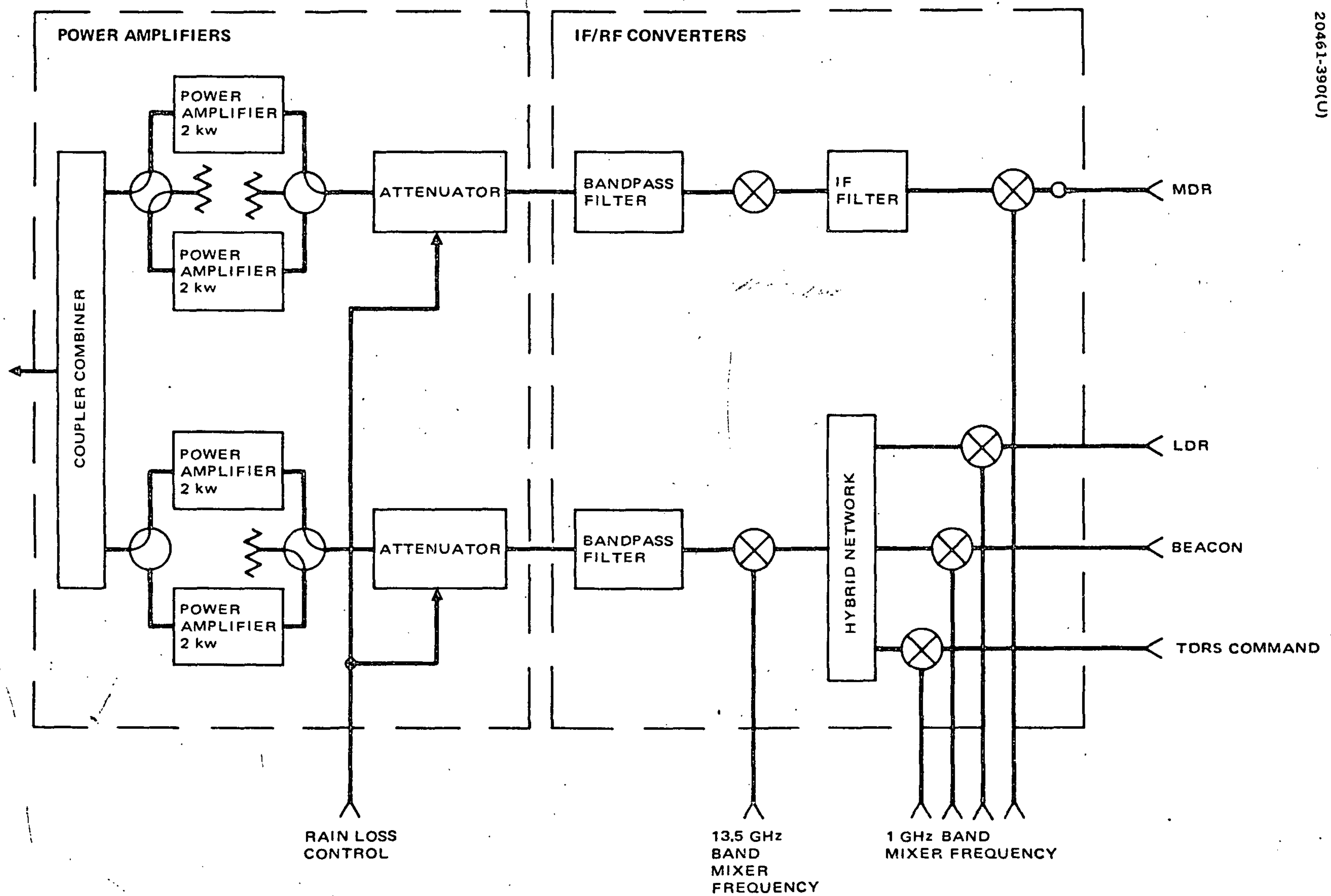
Receivers

- K band receiver
    1) Location, rear of reflector
    2) Noise figure, 3.9 dB
- VHF receiver
    1) Location, within terminal structure
    2) Noise figure, less than 4 dB
- UHF receiver
    1) Location, within terminal structure
    2) Noise figure, less than 4 dB
- Power Amplifiers
    1) Two 2 kw klystrons will be used
    2) The MDR signal is amplified in one with an output level of 1500 watts
    3) The LDR, beacon, and TDRS telemetry are added in a hybrid and amplified in the other with the following power allocations:
        a) LDR, 710 watts
        b) Beacon, 20 watts
        c) TDRS telemetry, 20 watts

Figure 3-13 shows the forward link RF/IF equipment and power amplifier arrangement.

3.4.2 Signal Processing

The ground station return signal processing equipment must separate the individual channels in the two signals from each terminal, demodulate the data signals, and then multiplex all data for transmission to the GSFC telecommunications control center. These functions are illustrated in Figure 3-14 where for simplicity range and range rate measurements have been made part of the general demodulation process. The forward signal processing as shown in Figure 3-15 includes demultiplexing the signals from GSFC, modulating the LDR and MDR with PN codes, IF carrier modulation of all signals, and transmission to the two terminals. The voice must be switched to the correct LDR or MDR channel as directed from GSFC.



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  2) Noise figure, less than 4 dB
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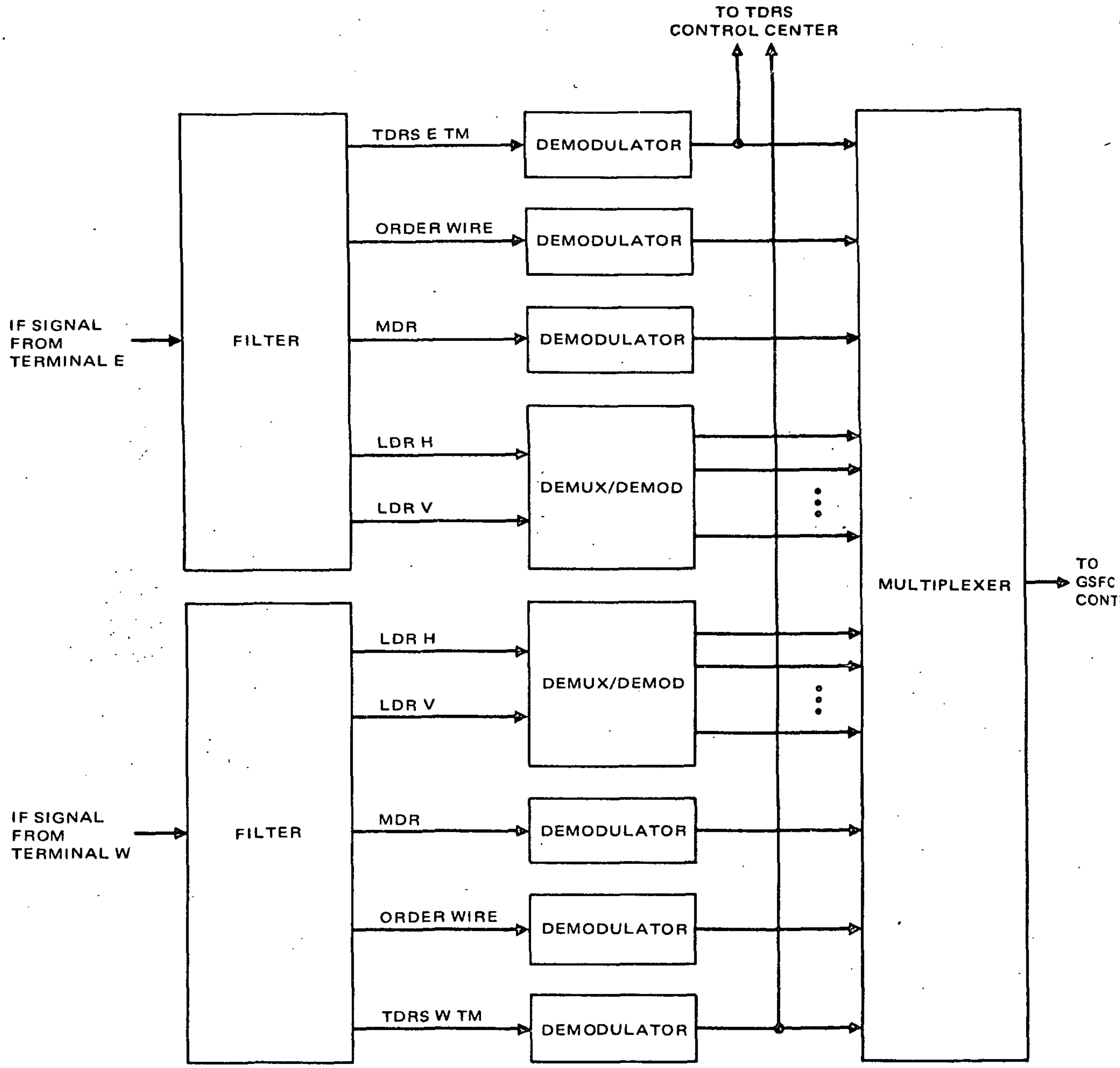

Figure 3-14. Ground Station Return Signal Processing

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    2) Noise figure, 3.9 dB
- VHF receiver
    1) Location, within terminal structure
    2) Noise figure, less than 4 dB
- UHF receiver
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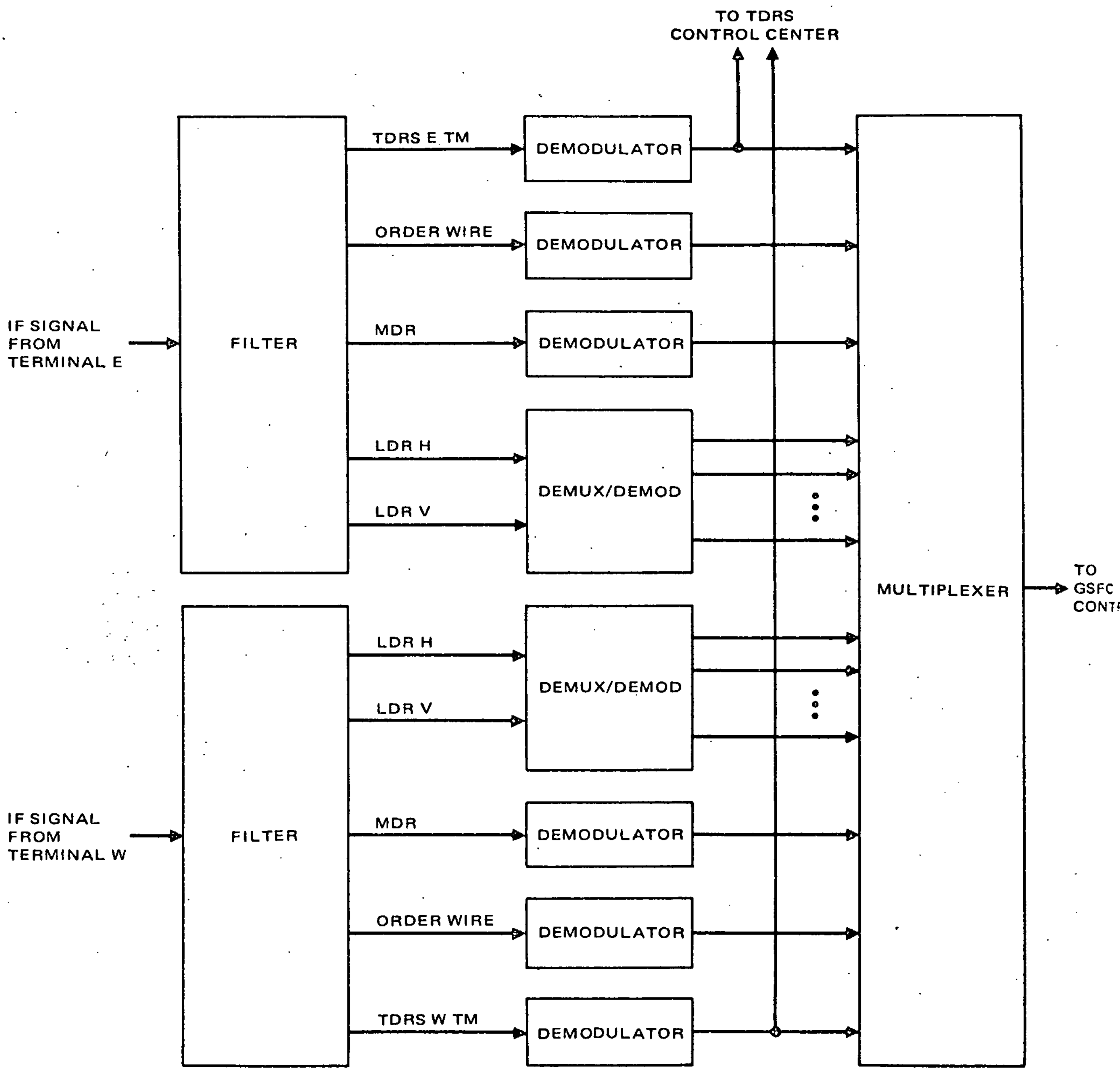

Figure 3-14. Ground Station Return Signal Processing

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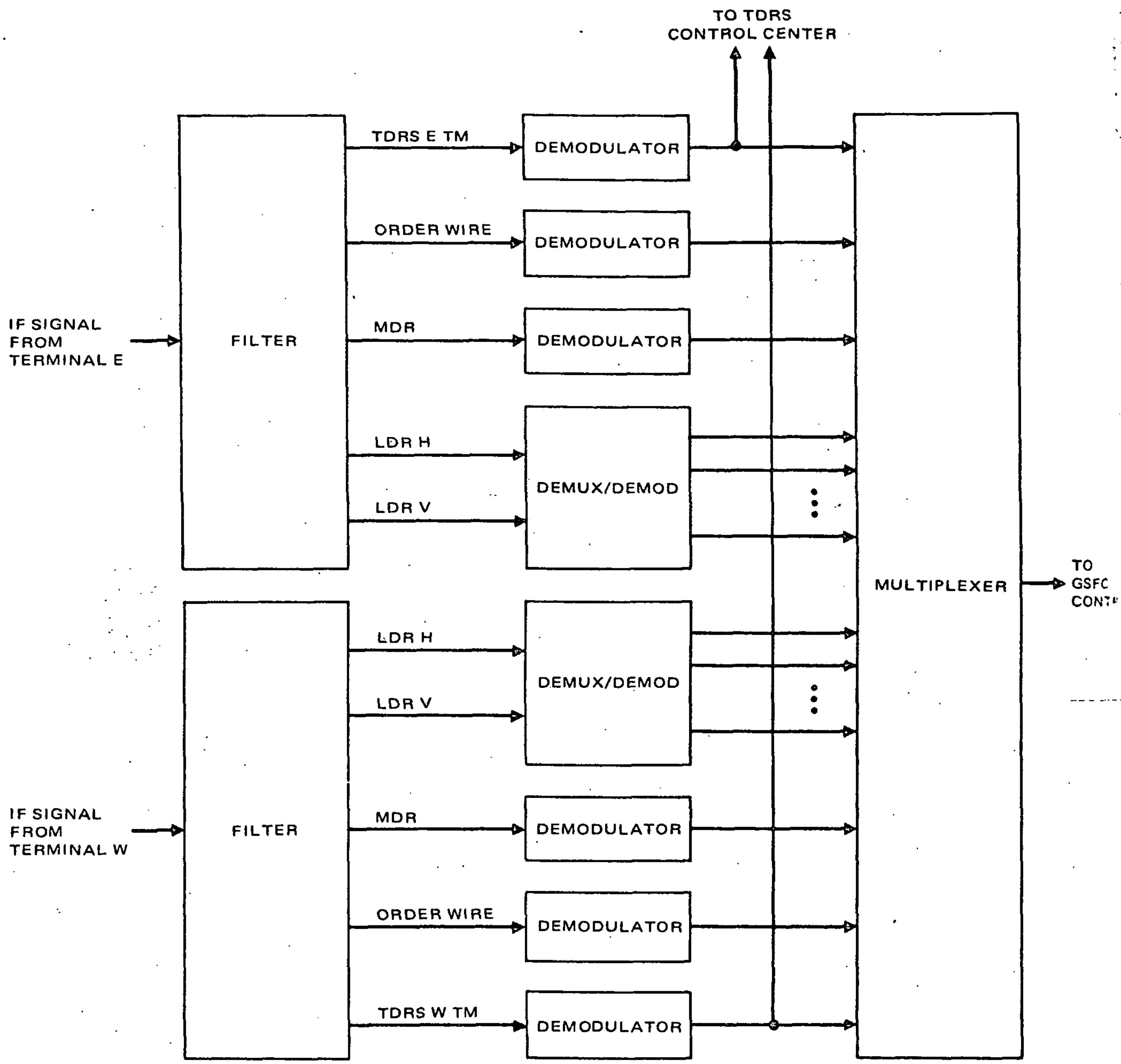


Figure 3-14. Ground Station Return Signal Processing

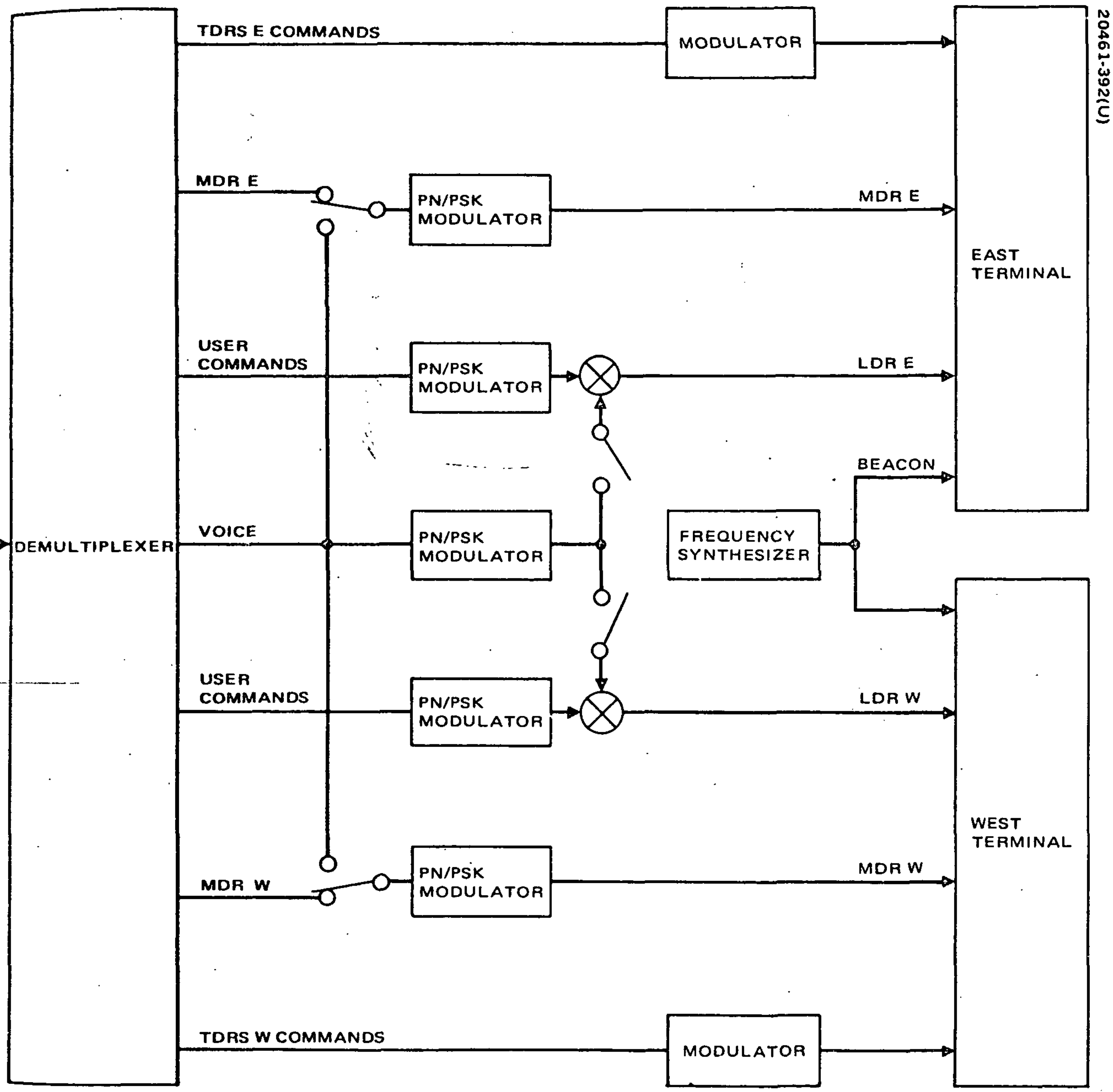


Figure 3-15. Ground Station Forward Signal Processing

The major task required for the signal processing equipment is one of the integration, control, checkout, maintenance, and replacement provision. All equipment, except the LDR return channel demultiplexing and demodulation equipment, is conceptually conventional. The equipment and major parameters follow.

Forward Links

- LDR telemetry PN/PSK modulator
  1) Quantity, 2
  2) Rate, 614.4 Kchips/sec
- LDR voice PN/PSK modulator
  1) Quantity, 2
  2) Rate, 614.4 Kchips/sec
- MDR PN/PSK modulator
  1) Quantity, 2
  2) Rate, 10 Mchips/sec
- TDRS telemetry
  1) Quantity, 2
  2) Type, three tone GSFC AM-FSK
  3) Bit rate, 128 bps

Return Links

- LDR telemetry — Notch filters shall be used to reduce RFI Data demodulators for each user are required consisting of the following basic units:
  1) One acquisition correlator
  2) Two pair of telemetry correlators
  3) One diversity combiner
  4) One convolutional decoder

5) One range measurement unit

6) One range rate measurement unit

- Output data rate, 1200 bps
- LDR voice

  1) Two biphase PSK demodulators

  2) One diversity combiner

  3) One rate one-half convolutional decoder

  4) Output bit rate 19.2 bps

- MDR — a biphase PSK correlation receiver must be used to demodulate the return signal and produce an output bit stream corresponding to the current user spacecraft telemetry rate; a standardized variable bit rate device is envisioned.

4. TDRS DESIGN DESCRIPTION

4.1 DESIGN CHARACTERISTICS

4.1.1 General

The TDRS employs a gyrostat configuration for attitude stabilization using the earth and sun as reference objects. It is compatible with a Delta 2914 launch vehicle and employs an apogee motor for injection into synchronous orbit. Hydrazine propulsion is provided for spin axis attitude control and orbital maneuvers. Power is generated by solar cells for sunlight operation and batteries provided for eclipse operations.

The spacecraft has two way communication equipment which allows communications with the ground station and with user satellites at VHF, UHF, S band, and K_u band frequencies.

An artist's conception of the TDRS is shown in Figure 4-1 and a configuration layout drawing is shown as Figure 4-2. A list of the TDRS salient characteristics is contained in Table 4-1.

4.1.2 Temperature Control

The spacecraft will experience heating during the launch phase. Heat transfer through the nose fairing will be controlled in accordance with the requirements specified in a spacecraft launch vehicle interface control document. After nose fairing ejection, the spacecraft will experience heating as a result of solar radiation, earth radiation, and aerodynamic heating. The heat capacitance and thermal design of the spacecraft will limit the temperature rise resulting from this heating to an acceptable value.

After injection into synchronous orbit, the temperature of all spacecraft elements will be maintained within the ranges specified in the subsystem functional requirements, including a period of solar eclipse not to exceed 72 minutes. Passive means of temperature control will be used as much as possible. A discussion of thermal control design is contained in subsection 4.3.9.

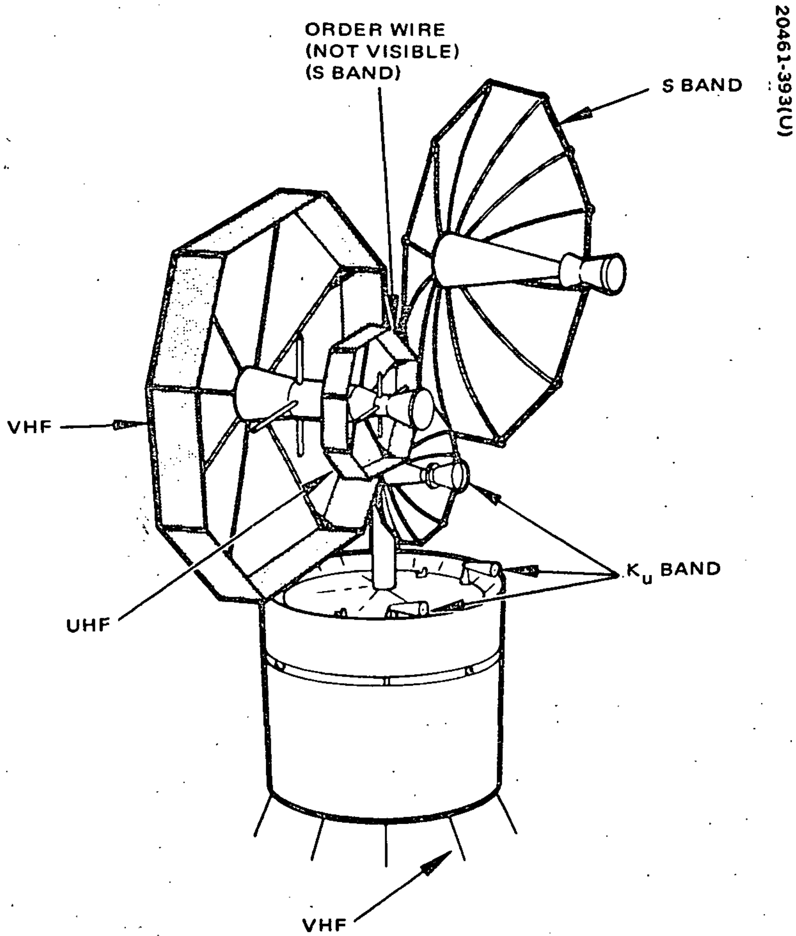


Figure 4-1. TDR Spacecraft

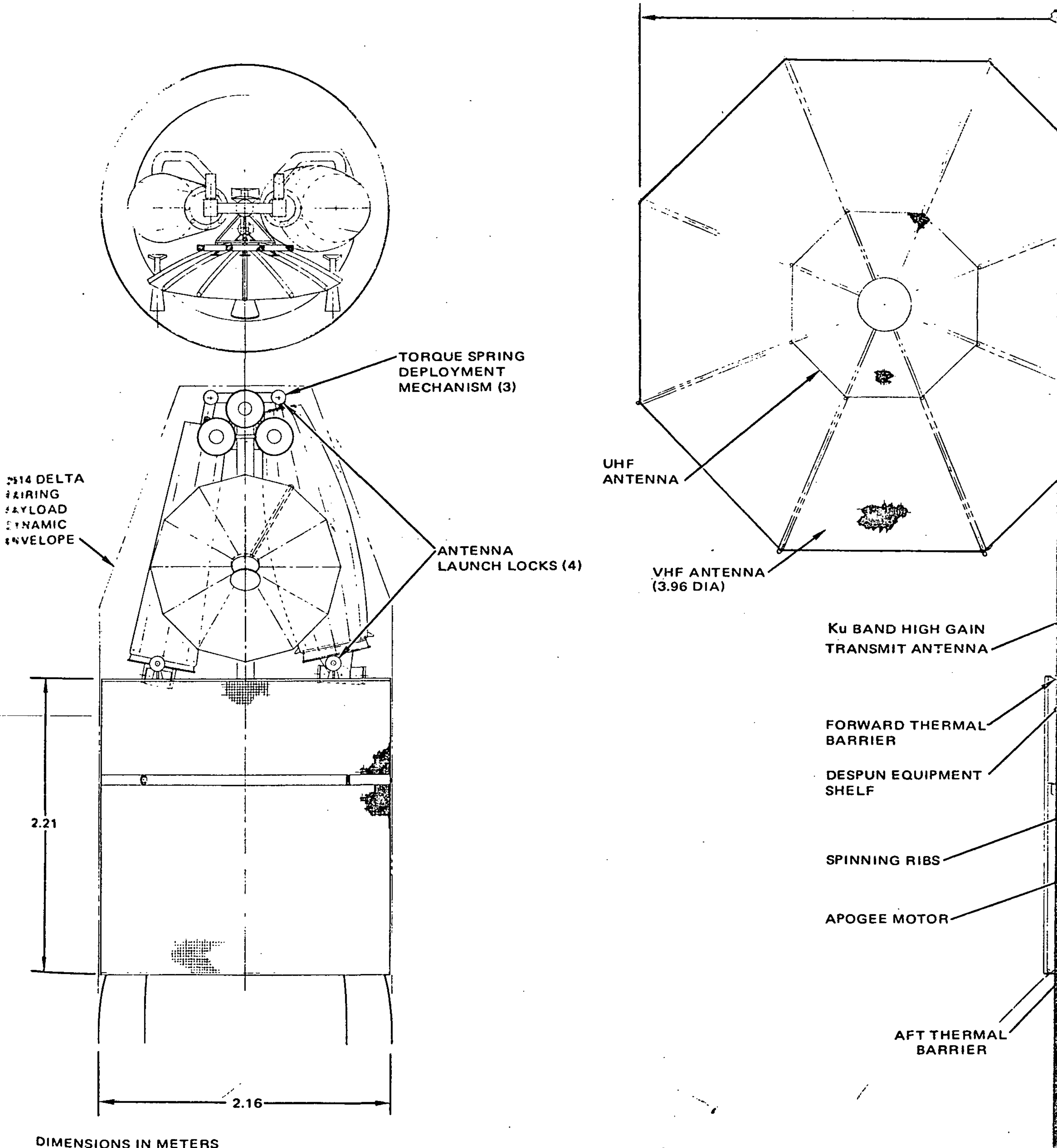
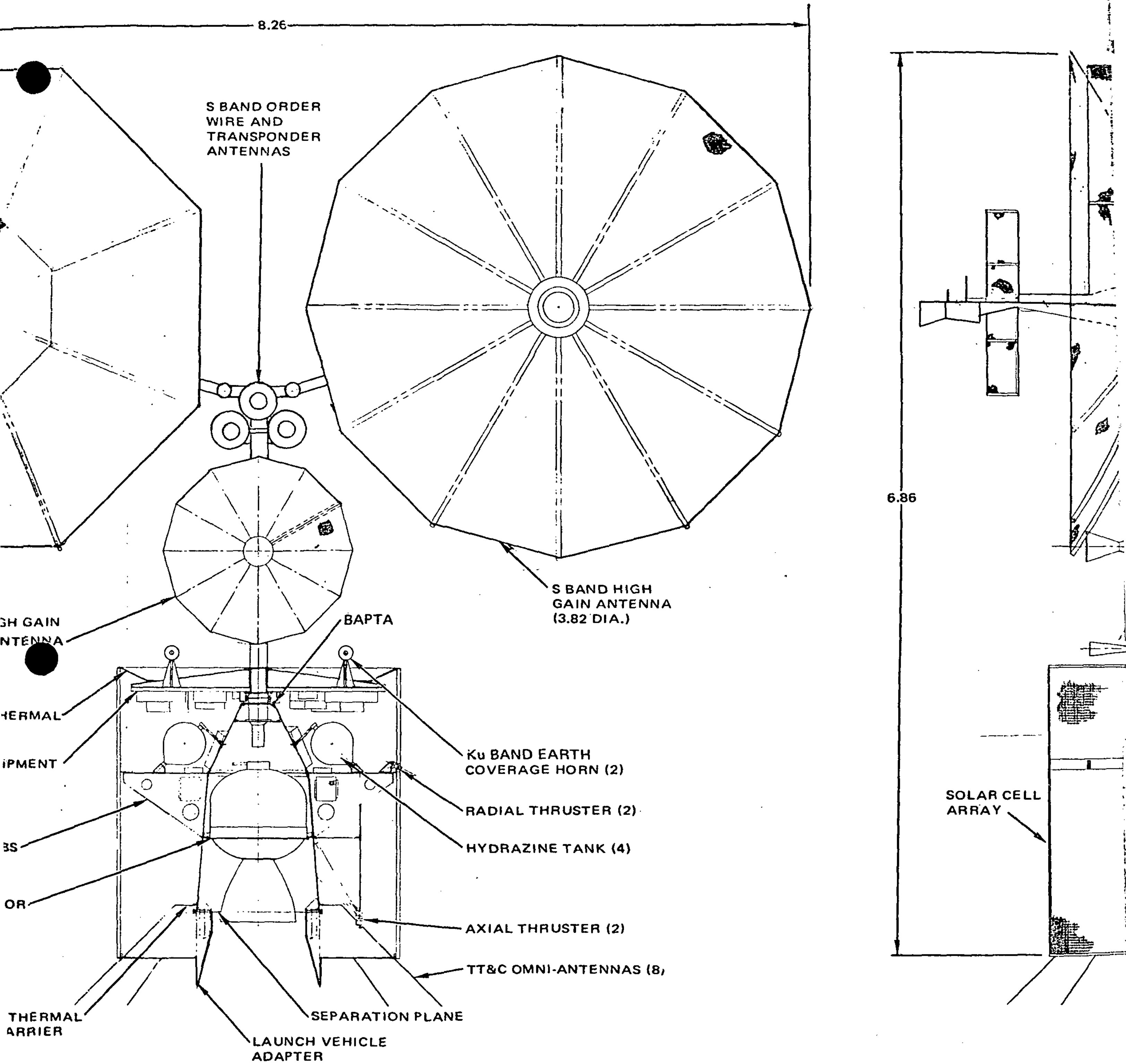


Figure 4-2. TDRS Configuration



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IPMENT
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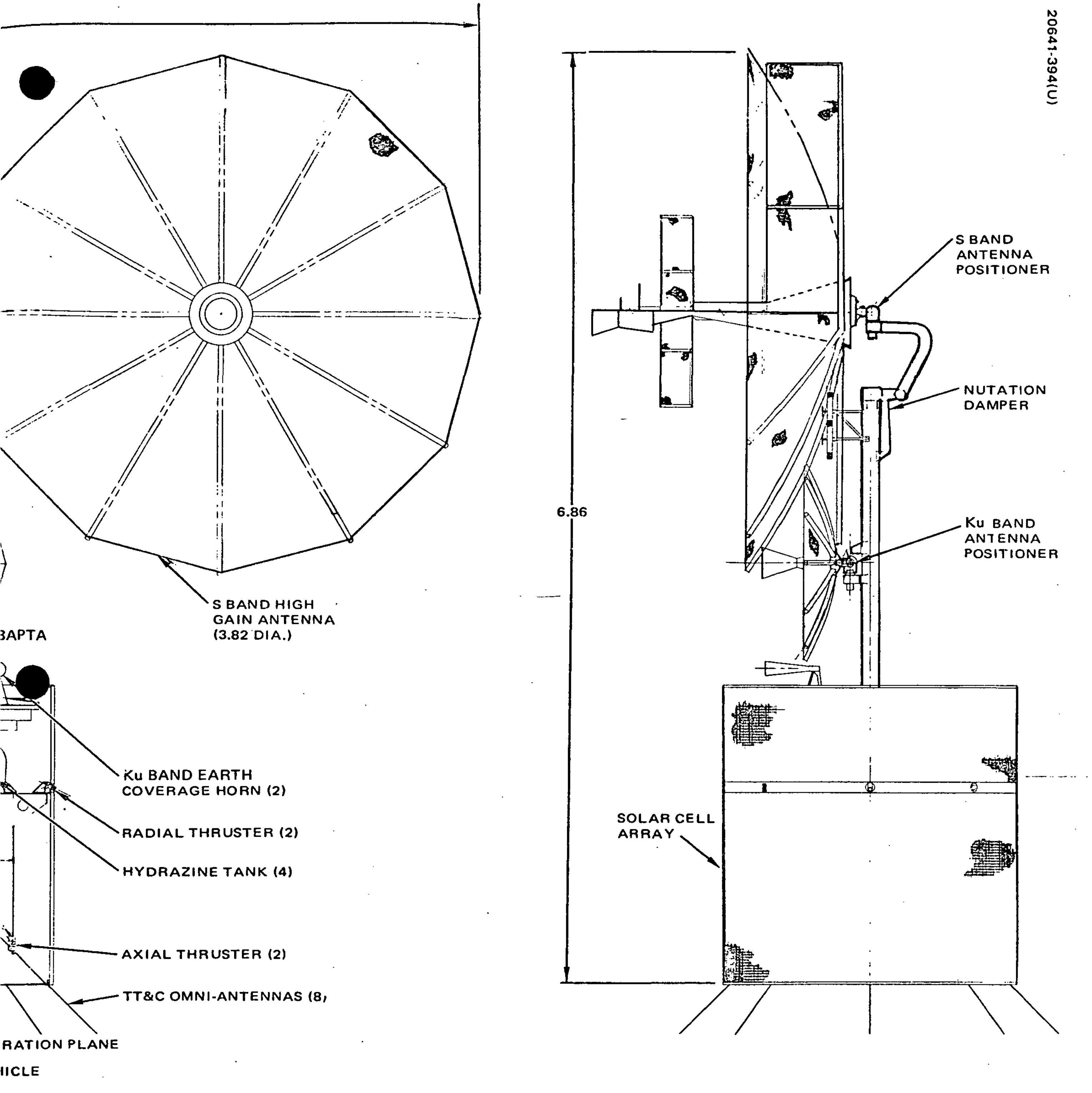
RADIAL THRUSTER (2)
SOLAR CELL ARRAY
BS
HYDRAZINE TANK (4)
OR
AXIAL THRUSTER (2)
TT&C OMNI-ANTENNAS (8)
THERMAL ARRIER
SEPARATION PLANE
LAUNCH VEHICLE ADAPTER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S BAND ANTENNA POSITIONER
NUTATION DAMPER
6.86
Ku BAND ANTENNA POSITIONER
SOLAR CELL ARRAY

TABLE 4-1. GENERAL SUMMARY

GENERAL	
Orbit	Synchronous, 7 deg initial inclination
Launch vehicle	Delta 2914
Payload fairing	Standard 2.44 m fairing (8 ft)
Design lifetime	5 yr
Reliability	0.717 at 5 yr
Station change maneuver	2 maneuvers, 4.5 deg/day
CONFIGURATION	
Stabilization	Hughes Gyrostat
Despun section subsystems	Antennas
Spinning section subsystems	Repeaters Portion of TT&C Electrical power Propulsion Attitude control Portion of TT&C
STRUCTURE	Uses aluminum and beryllium
Nominal dimensions, meters	
• Height x width (antennas deployed)	6.86 x 8.26 m
• Diameter (rotor)	2.16 m
Mass, end of 5 yr (dry),	347 kg
THERMAL CONTROL	Thermal control cavity inside spinning solar cell array – passive design
TELECOMMUNICATION SUBSYSTEM	
Low data rate user command	30 dBw EIRP, 400.5 to 401.5 MHz
UHF voice	30 dBw EIRP, 400.5 to 401.5 MHz
Medium data rate user command	41 dBw EIRP, 2035 to 2120 MHz
S band voice	47 dBw EIRP, 2035 to 2120 MHz
Ku band return link	51 dBw EIRP, 13.4 to 14.0 GHz
Low data rate receive sensitivity	-16 dB/K
Medium data rate receive sensitivity	8 dB/K
Order wire receiver sensitivity	-13 dB/K
Ku band forward link sensitivity	-15 dB/K

TABLE 4-1 (continued)

TELEMETRY SUBSYSTEM	
PCM mode	
• Word length	8 bits
• Frame length	64 words
• Analog	48 words
• Digital words	16
• Bit rate	1000 bits/sec
• Code type output	Manchester
FM mode (attitude data)	
• Subcarrier frequency	14.5 kHz
• Data type	Real time pulses
• Modulation	FM
• Data transmitted	1) Sun pulses 2) North earth pulses 3) South earth pulses 4) Execute receipt
COMMAND SUBSYSTEM	
Tones	1, 0, and execute
Input signal	FSK/AM
Bit rate	128 bits/sec
Command capacity,	255 maximum
Command verification via	Telemetry
Command execution	Real time
Execution synchronization	Sun or earth pulses
Maximum command rate	Approximately 4 per second
ANTENNA SUBSYSTEM	
Low data rate service antennas (VHF and UHF)	Short backfire type, 12 dB
Medium data rate service antenna	Paraboloid reflector type, 36 dB
TDRS to ground link, Ku band	Paraboloid reflector type, 44 dB
Ground to TDRS link, Ku band	Two horns, 16 dB
VHF backup T&C link	Turnstile omni, -13 dB over 97% of sphere
Order wire service	Short backfire type, 13dB
S band transponder	Two short backfire type

TABLE 4-1 (continued)

ATTITUDE CONTROL SUBSYSTEM	
Stabilization type	Gyrostat type dual spin
Nutation control	Magnetic damper and despin control dynamics
Despin control	Earth center finding with earth sensors
Control accuracy	0.5 deg
Power and signal transfer	Dry lubricated, silver slip rings
Despin motor	Two, independent, brushless dc, resolver commutated
REACTION CONTROL SUBSYSTEM	
Propellant	Hydrazine
Thrusters	Two 22N radial, two 4.5 N axial thrusters
ELECTRICAL POWER SUBSYSTEM	
Sunlit power	(26.5 v)
• Equinox, EOL	404 watts
• 23 days before equinox (EOL)	399 watts
• Summer solstice (EOL)	364 watts
• Maximum power required	438 watts (requires augmentation by batteries)
• Maximum bus voltage	30 volts (clamped by bus limiters)
Solar cells	
• Number	33,048
• Type	2 x 2 cm, silicon N/P, 10 ohm-cm
• Thickness	0.18 mm (7.2 mil)
• Cover glass	0.15 mm (6 mil)
Eclipse power	350 w average (< 60% DOD)
Batteries	
• Number	Two
• Type	Nickel-cadmium
• Capacity	16 amp-hr
• Maximum DOD	<60%
• Augmentation DOD	4.5%
• Charge rate	c/15
• Trickle charge rate	c/60
• Minimum bus voltage	24.5 v

f sphere

TABLE 4-1 (continued)

Electronics	
Battery charge controller operation	Automatic or ground commanded
Battery discharge controller operation	Automatic
Battery reconditioning	On ground command (optional)
Tap limiters; operating voltage	29 to 29.5 v
Bus limiters; operating voltage	29.5 to 30 v
APOGEE INJECTION MOTOR	
Type	Solid propellant, I_{sp} = 302 sec
Velocity of injection	1670 m/s for 680 kg separation mass

4.1.3 Electrical Power

The spacecraft generates sufficient electrical power via solar cells and batteries (as discussed in subsection 4.3.6) to provide all subsystem needs. A breakdown of the power needs is shown in Tables 4-2 and 4-3.

4.1.4 Mass

The mass of the spacecraft (less adapter) is less than the 680.4 kilogram (1500 pounds) capability of the booster. A contingency of 25.6 kg is available for subsystem growth. An overall summary of the subsystem masses is contained in Table 4-4. A complete list of all hardware is contained in Table 4-5.

4.1.5 Telemetry, Tracking, and Command

A total capability of 62 words are provided for telemetry and 254 commands. Lists of telemetry and command requirements are provided in Tables 4-6 and 4-7, respectively.

4.1.6 Reliability

The probability that the TDRS will meet the specified requirements for a period of 5 years in orbit is 0.717. Table 4-8 gives a breakdown by subsystem.

TABLE 4-2. TDRS ELECTRICAL POWER SUMMARY, WATTS (ECLIPSE SEASON)

TABLE 4-2. TDRS ELECTRICAL POWER SUMMARY, WATTS (ECLIPSE SEASON)

Mode	Command	Intermittent S Band Voice	Intermittent UHF Voice	Command	Intermittent S Band Voice	Intermittent UHF Voice
Illumination	Sunlight			None		
Power Source	Solar at 27.5 Volts	Solar at 27.5 Volts	Solar and Battery at 25.5 Volts	Battery at 25.5 Volts	Battery at 25.5 Volts	Battery at 25.5 Volts
Percent Operating Time	50 to 75*	50*	25*	50 to 75*	50*	25*
Frequency Synthesizer	8.0	8.0	7.4	7.4	7.4	7.4
K band equipment	36.0	36.0	33.5	33.5	33.5	33.5
UHF/VHF equipment						
Command and data	157.8	157.8	146.1	146.1	146.1	146.1
Voice	--	--	142.0	--	--	142.0
S band equipment						
Command data	24.0	--	22.2	22.2	--	22.2
Voice	--	96.3	--	--	89.5	--
Telemetry Equipment	15.6	15.6	14.5	14.5	14.5	14.5
Antenna position control	6.0	6.0	6.0	6.0	6.0	6.0
Despin control	19.7	19.7	18.3	18.3	18.3	18.3
Thermal control	5.6	5.6	4.6	4.6	4.6	4.6
Power electronics	18.0	11.0	20.0	40.0	45.0	50.0
Battery charging	60.0	--	--	--	--	--
Distribution losses	8.0	8.0	9.0	7.0	8.0	9.0
Reserve power	40.3	35.0	--	--	--	--
Power available or required	399.0	399.0	416.4	292.2	359.5	453.6

*Either the UHF or the S band voice transmitter operates but not both simultaneously.

TABLE 4-3. TDRSS ELECTRIC POWER SUMMARY DURING SUMMER SOLTICE

Mode	Command	Intermittent S Band Voice	Intermittent UHF/VHF Voice
Power Source	Solar at 27.5 Volts	Solar at 27.5 Volts	Solar and Battery at 25.5 Volts
Percent Operating Time	50 to 75*	50*	25*
Frequency Synthetizer	8.0	8.0	7.4
K band equipment	36.0	36.0	33.5
UHF/VHF equipment			
Command and data	157.8	157.8	146.1
Voice	-	-	142.0
S band equipment			
Command data	24.0	-	22.2
Voice	-	96.3	-
Telemetry equipment	15.6	15.6	14.5
Antenna position control	6.0	6.0	6.0
Despin control	19.7	19.7	18.3
Thermal control	5.6	5.6	4.6
Power electronics	14.8	11.0	30.0
Battery charging	37.5	-	-
Distribution losses	8.0	8.0	9.0
Reserve power	31.0	-	-
Power available or required	364.0	364.0	433.6

*Either the UHF or the S band voice transmitter operates but not both simultaneously.

4.1.7 Useful Life

The minimum useful life is 5 years in the synchronous orbit assigned, preceded by 1 year of storage handling test and launch under the applicable environmental conditions:

- The spacecraft will be subjected to the acoustic field, vibration, shock, and acceleration generated by a Delta 2914 launch vehicle.
- During the normal orbit phase and normal orbit eclipse phase, temperatures will be encountered as specified in 4.3.9.

TABLE 4-4. TDR SATELLITE MASS SUMMARY

Subsystem	Mass, kg
Repeater	55.1
Telemetry and command	18.1
Antenna	36.6
Attitude control	23.5
Reaction control	11.4
Electrical power	61.5
Wire harness	11.5
Apogee motor, burned out	25.5
Structure	68.2
Thermal control	10.0
Contingency	25.6
Final mass in orbit	347.0
Hydrazine	38
Initial mass in orbit	385.0
Apogee motor expendables	293
Separation mass	678.0

- Radiation environment includes trapped electrons and protons as defined by NASA radiation maps AE3 and AP5 and solar flare protons described by a Hughes model.

- The design of the spacecraft will be such that it is insensitive to estimated external electromagnetic environments. The EMI generated by any of the spacecraft subsystems shall be suppressed such that it does not interfere with the operations of any other spacecraft subsystems. Adequate margins of safety shall be required and verified during system test.

- Exposure to a hard vacuum of 10^{-12} torr will occur.

TABLE 4-5. TDR SATELLITE HARDWARE

Subsystem/Item	Quantity	Total Mass, kg	Comments
Repeater subsystem		55.1	
Receiver, K_u band	2	2.6	
Transmitter, K_u band	2	4.1	
Upconverter, K_u band	2	0.8	
Receiver, S band	2	1.4	
Order wire recorder, S band	2	1.9	
Transmitter, S band	2	7.3	
Receiver, VHF	2	4.0	
Transmitter, UHF	2	17.2	
Frequency synthesizer	2	8.2	
S band transponder	2	7.6	
Telemetry and Command subsystem		18.1	
Despun decoder	2	2.7	HS 312
Despun encoder	2	3.2	HS 312
Despun squib driver	1	0.5	HS 312
Dual transponder	2	3.1	HS 333
Diplexer	1	0.5	
Spin decoder	2	2.7	HS 312
Spin encoder	2	4.0	HS 312
Squib and solenoid driver	1	0.9	HS 320
Latching valve/heater driver	1	0.5	HS 312
Antenna subsystem		36.6	
Parabolic reflector, K_u band	1	1.4	
Horn, K_u band	2	0.5	
Parabolic reflector, S band	1	8.3	
VHF/UHF backfire type	1	7.9	
Order wire, backfire type		0.5	
VHF turnstile array	8	1.0	ATS
Antenna positioner	2	8.4	HS 318

TABLE 4-5 (continued)

Subsystem/Item	Quantity	Total Mass, kg	Comments
Positioner controllers	2	1.8	HS 318
Coax and waveguide		6.8	
Attitude control subsystem		23.5	
BAPTA	1	15.0	
Earth sensors	3	2.2	HS 312
Sun sensor	1	0.1	HS 312
Despin control electronics	2	3.6	HS 312
Accelerometers	2	0.3	HS 312
Nutation damper	1	2.3	HS 312 scaled
Reaction control subsystem		11.4	
Tanks	4	6.0	HS 333
Thrusters	4	1.7	HS 333/312
Miscellaneous		2.7	HS 333
Pressurant		1.0	
Electrical power subsystem		61.5	
Solar cell array		20.0	
Batteries	2	28.6	HS 312
Battery discharge controllers	2	9.1	HS 318
Battery charge controllers	2	0.9	HS 312
Voltage limiters	6	2.7	HS 308
Current sensor	1	0.2	HS 318
Wire harness		11.5	
Apogee motor burned out		25.5	

TABLE 4-5 (continued)

Subsystem/Item	Quantity	Total Mass, kg	Comments
Structure		68.2	
Thrust cone assembly		19.5	
Substrate		23.7	
Despun compartment		10.0	
Antenna support		8.2	
TCS tank and thruster support		4.5	
Balance weights		2.3	
Thermal control		10.0	
Forward sun shield		2.0	
Aft barrier		2.9	
RCS tank wrap		0.6	HS 333
RCS lines, valves, heaters		0.5	HS 312
Thruster heat shield		0.1	HS 312
Apogee blanket		0.7	
Paint		1.5	
Despun sun shield		0.7	
Despun mast blanket		1.0	

4.2 INTERFACES

4.2.1 Internal

The major internal functional interfaces among the various subsystems of the spacecraft are shown in the TDR spacecraft functional block diagram in Figure 4-3.

4.2.2 Ground Station

The TDRS is compatible in frequency, power level, and sensitivity with the RF equipment located at the GSFC ground station.

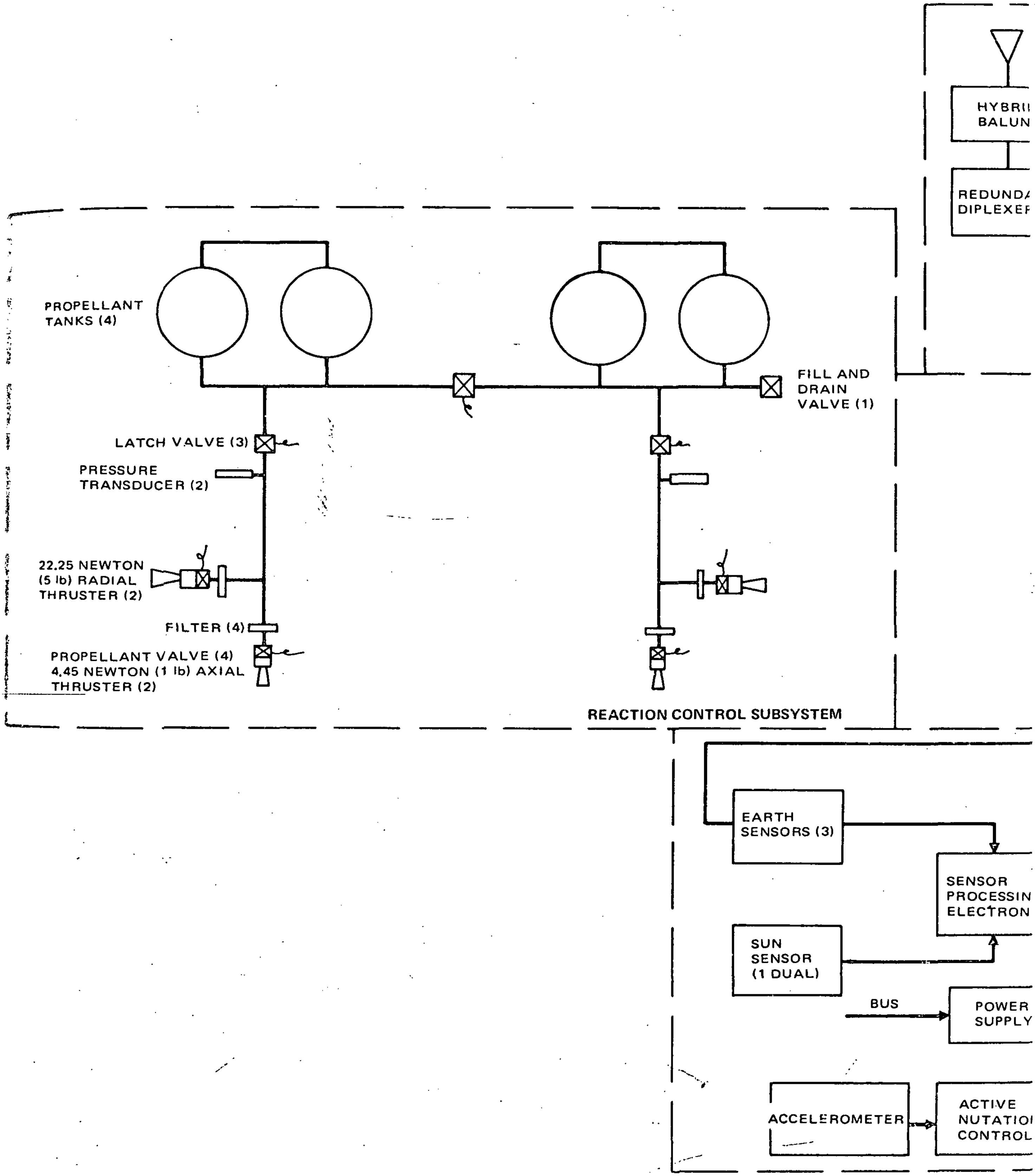
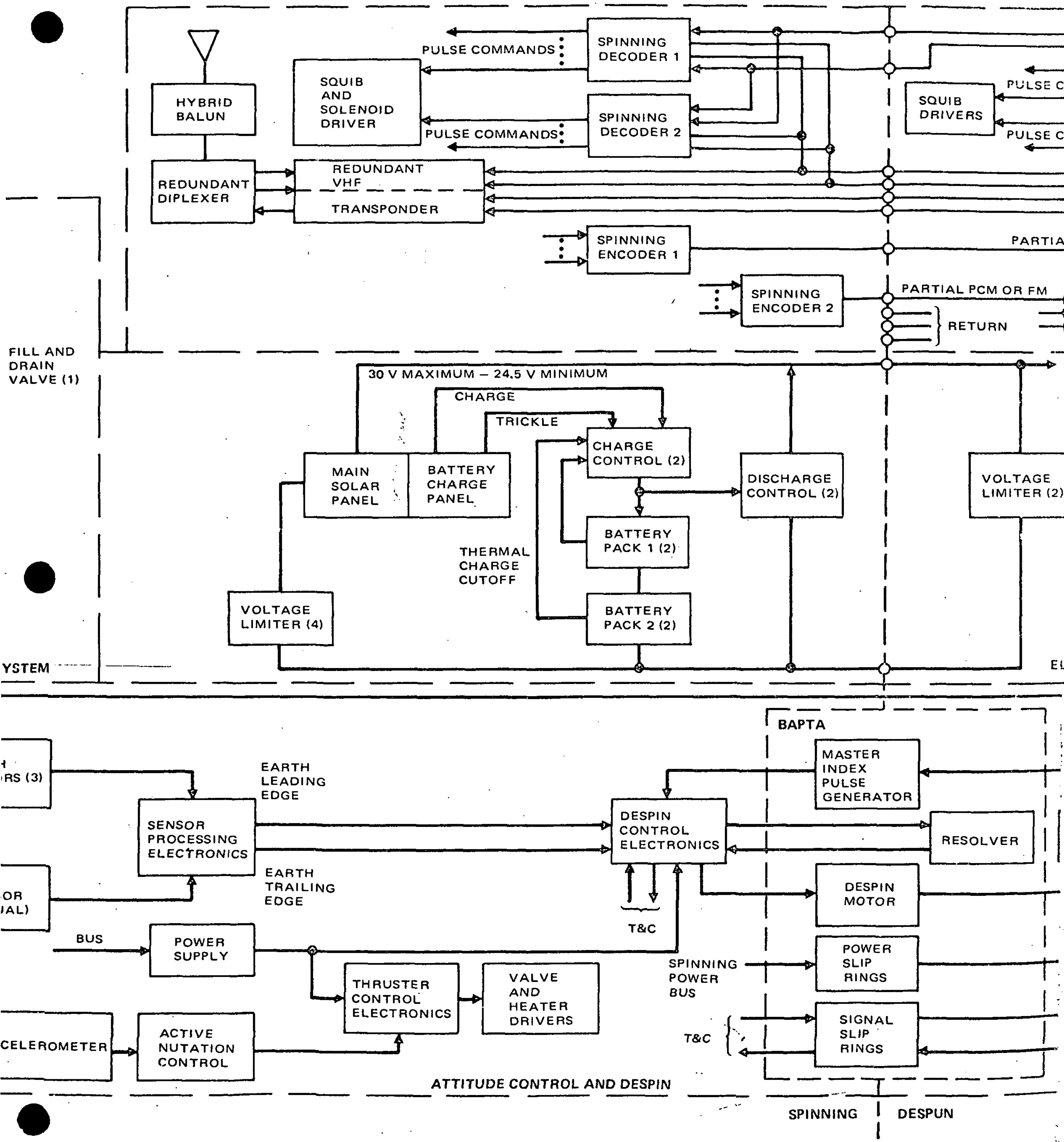
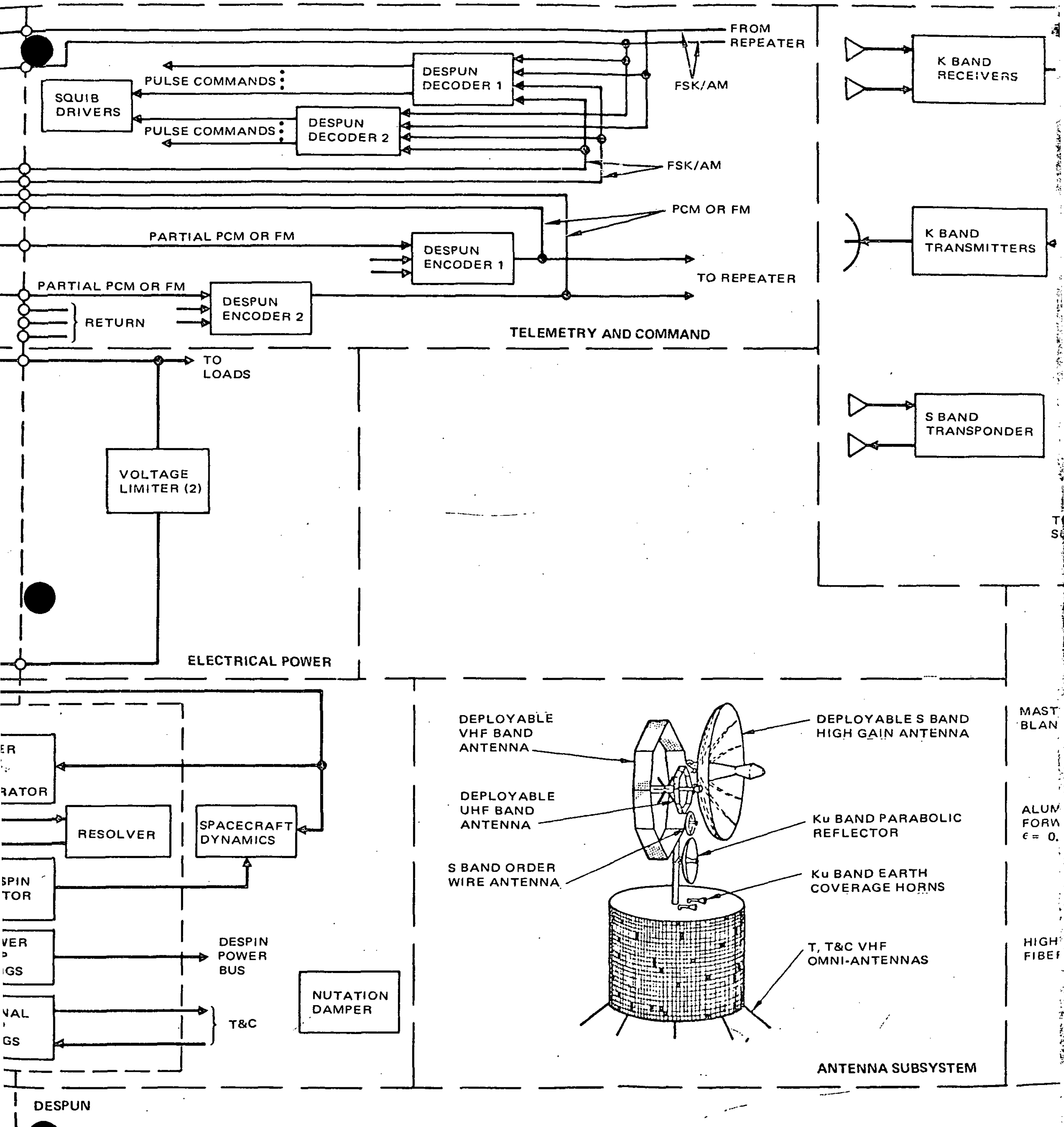
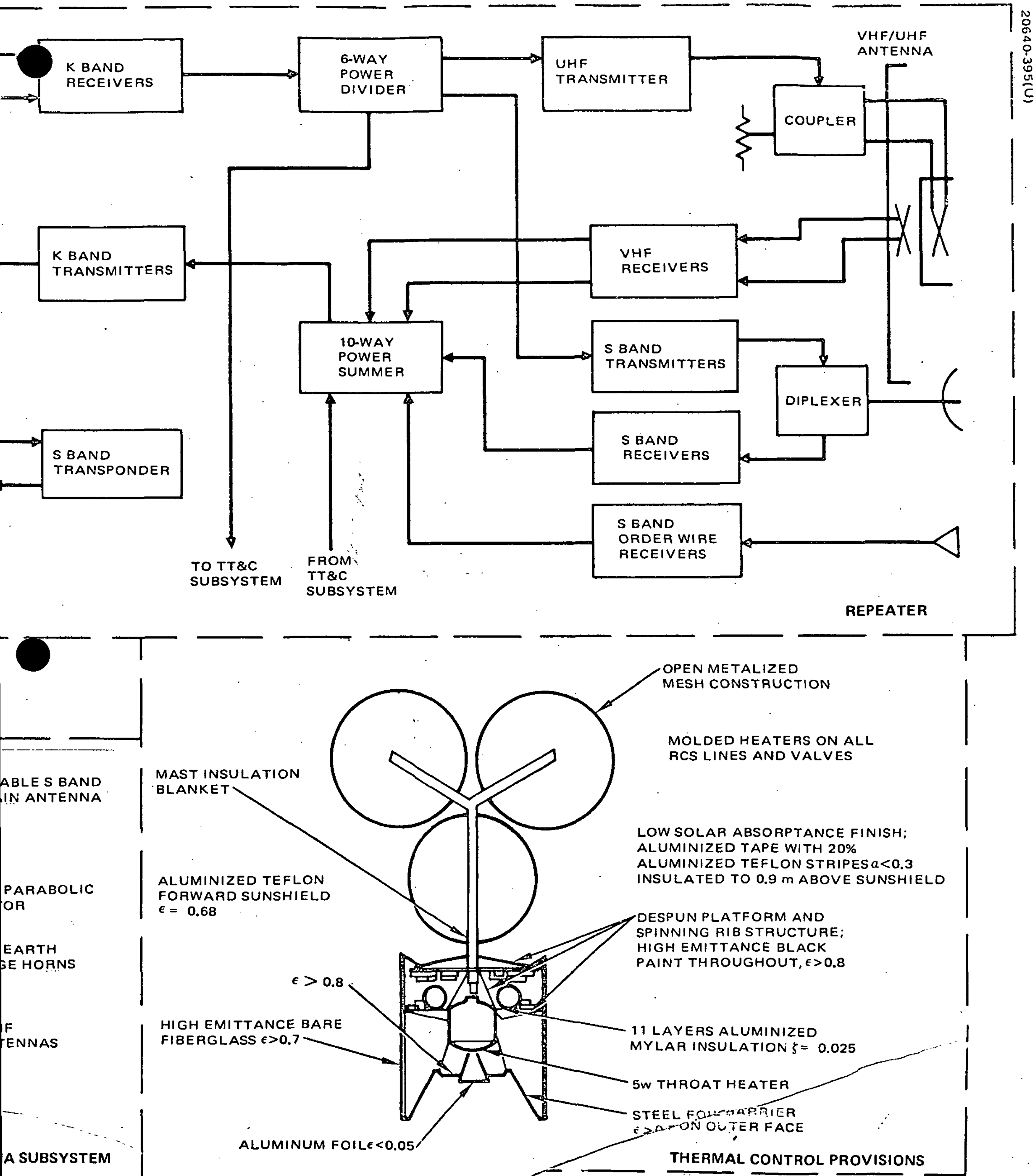


Figure 4-3. TDR Spacecraft Functional Block Diagram


HYBRID BALUN
SQUIB AND SOLENOID DRIVER
PULSE COMMANDS
SPINNING DECODER 1
SPINNING DECODER 2
SQUIB DRIVERS
PULSE C
REDUNDANT DIPLEXER
REDUNDANT VHF TRANSPONDER
SPINNING ENCODER 1
PARTIAL
SPINNING ENCODER 2
PARTIAL PCM OR FM
RETURN
FILL AND DRAIN VALVE (1)
30 V MAXIMUM – 24.5 V MINIMUM
CHARGE
TRICKLE
CHARGE CONTROL (2)
MAIN SOLAR PANEL
BATTERY CHARGE PANEL
DISCHARGE CONTROL (2)
VOLTAGE LIMITER (2)
BATTERY PACK 1 (2)
THERMAL CHARGE CUTOFF
VOLTAGE LIMITER (4)
BATTERY PACK 2 (2)
YSTEM
EL
BAPTA
MASTER INDEX PULSE GENERATOR
RS (3)
EARTH LEADING EDGE
SENSOR PROCESSING ELECTRONICS
DESPIN CONTROL ELECTRONICS
RESOLVER
EARTH TRAILING EDGE
OR
IAL)
DESPIN MOTOR
T&C
BUS
POWER SUPPLY
SPINNING POWER BUS
POWER SLIP RINGS
THRUSTER CONTROL ELECTRONICS
VALVE AND HEATER DRIVERS
CELEROMETER
ACTIVE NUTATION CONTROL
SIGNAL SLIP RINGS
ATTITUDE CONTROL AND DESPIN
SPINNING
DESPUN


FROM
REPEATER
FSK/AM
SQUIB
DRIVERS
PULSE COMMANDS
DESPUN
DECODER 1
DESPUN
DECODER 2
PULSE COMMANDS
FSK/AM
PCM OR FM
PARTIAL PCM OR FM
DESPUN
ENCODER 1
TO REPEATER
PARTIAL PCM OR FM
DESPUN
ENCODER 2
RETURN
TELEMETRY AND COMMAND
K BAND
RECEIVERS
K BAND
TRANSMITTERS
S BAND
TRANSPONDER
TO
LOADS
VOLTAGE
LIMITER (2)
ELECTRICAL POWER
RESOLVER
SPACECRAFT
DYNAMICS
DESPIN
POWER
BUS
T&C
NUTATION
DAMPER
DESPUN
DEPLOYABLE
VHF BAND
ANTENNA
DEPLOYABLE
UHF BAND
ANTENNA
S BAND ORDER
WIRE ANTENNA
DEPLOYABLE S BAND
HIGH GAIN ANTENNA
Ku BAND PARABOLIC
REFLECTOR
Ku BAND EARTH
COVERAGE HORNS
T, T&C VHF
OMNI-ANTENNAS
ANTENNA SUBSYSTEM


20640-395(U)
K BAND RECEIVERS
6-WAY POWER DIVIDER
UHF TRANSMITTER
VHF/UHF ANTENNA
COUPLER
K BAND TRANSMITTERS
VHF RECEIVERS
10-WAY POWER SUMMER
S BAND TRANSMITTERS
DIPLEXER
S BAND RECEIVERS
S BAND TRANSPONDER
S BAND ORDER WIRE RECEIVERS
TO TT&C SUBSYSTEM
FROM TT&C SUBSYSTEM
REPEATER
ABLE S BAND
IN ANTENNA
PARABOLIC
OR
EARTH
E HORNS
F
ENNAS
A SUBSYSTEM
OPEN METALIZED MESH CONSTRUCTION
MOLDED HEATERS ON ALL RCS LINES AND VALVES
MAST INSULATION BLANKET
LOW SOLAR ABSORPTANCE FINISH; ALUMINIZED TAPE WITH 20% ALUMINIZED TEFLON STRIPES α<0.3 INSULATED TO 0.9 m ABOVE SUNSHIELD
ALUMINIZED TEFLON FORWARD SUNSHIELD ε = 0.68
DESPUN PLATFORM AND SPINNING RIB STRUCTURE; HIGH EMITTANCE BLACK PAINT THROUGHOUT, ε>0.8
ε > 0.8
HIGH EMITTANCE BARE FIBERGLASS ε>0.7
11 LAYERS ALUMINIZED MYLAR INSULATION ζ = 0.025
5w THROAT HEATER
STEEL FOIL BARRIER
ON OUTER FACE
ALUMINUM FOIL ε<0.05
THERMAL CONTROL PROVISIONS

User Satellites

The TDRS is compatible in frequency power level and sensitivity with equipment located in the orbiting user satellites.

Launch Vehicle

The TDRS is electrically and mechanically compatible with the interface requirements of the Delta 2914 launch vehicle.

TABLE 4-6. TDRSS PCM TELEMETRY CHANNEL ASSIGNMENTS

Frame Word	Spinning	Despun
0	Frame sync	
1		Frame sync
2	Decoder 1 command verify(1)	
3		Decoder 1 command verify(1)
4	Decoder 2 command verify(1)	
5		Decoder 2 command verify(1)
6	Status word 6 Execute Separation/spin up Time of day Parallel relay	
7		Status word 7 Execute Encoder identifier
8	Status word 8 Sun/earth select Despin electronics Bypass relays	
9		Status word 9 Frequency synthesizer status
10	Attitude determination	
11		Status word 11 Frequency synthesizer status
12	Attitude determination	
13		Status word 13 Communications status

TABLE 4-6 (continued)

Frame Word	Spinning	Despun
14	Attitude determination	
15		Status word 15 Communications status
16	Telemetry calibration	
17		Telemetry calibration
18	Bus Current	
19		Bus voltage
20	Bus voltage	
21		Spare
22	Battery A voltage	
23		Antenna azimuth C/D***
24	Battery B voltage	
25		Antenna elevation C/D***
26	Battery pack 1 temperature	
27		BAPTA hub temperature 1/2*
28	Battery pack 2 temperature	
29		UHF command transmitter temperature A/B*
30	Charge/discharge A current	
31		UHF voice transmitter temperature A/B*
32	Charge/discharge B current	Aft shelf temperature (B)*
33		S band transmitter temperature A/B*
34	Battery pack 1 temperature	
35		Platform temperature 1/2*
36	Battery Pack 2 temperature	
37		Auxiliary battery voltage
38	Radial jet 1/2 temperature*	
39		K band transmitter temperature A/B*

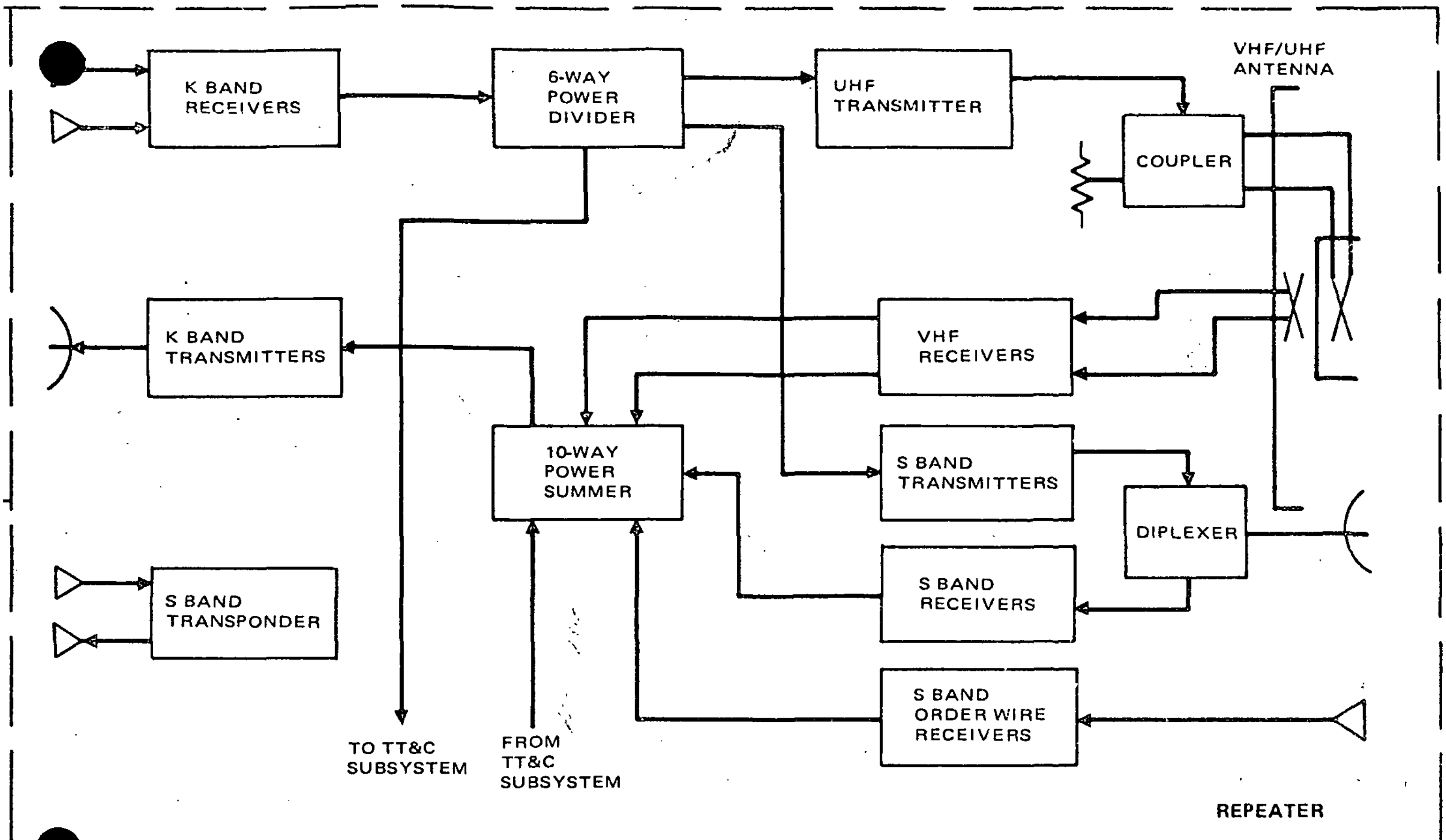
TABLE 4-6 (continued)

Frame Word	Spinning	Despun
40	Axial jet 1/2 temperature*	
41		Heater bank A current
42	Spare	
43		Heater bank B current
44	Fuel tank 1/2 temperature*	
45		Heater bank C current
46	Hydrazine 1 pressure	
47		Heater bank D current
48	Hydrazine 2 pressure	
49		Spare
50	Motor torque command**	
51		Spare
52	BAPTA temperature 1/2*	
53		Spare
54	Despin position torque command**	
55		Spare
56	Solar panel temperature 1	
57		Spare
58	Solar panel temperature 2	
59		Spare
60	Apogee motor temperature 1/2*	
61		Spare
62	Sunshield temperature 1/2*	
63		Spare

*No. 1 or A input on encoder 1; No. 2 or B input on encoder 2.

**Both torque command signals are connected to each encoder via OR circuits, since only one despin control electronics unit is on at a time.

***Antenna C (west) on encoder 1; antenna D (east) on encoder 2. Digital output increase when antenna steers toward north or west.



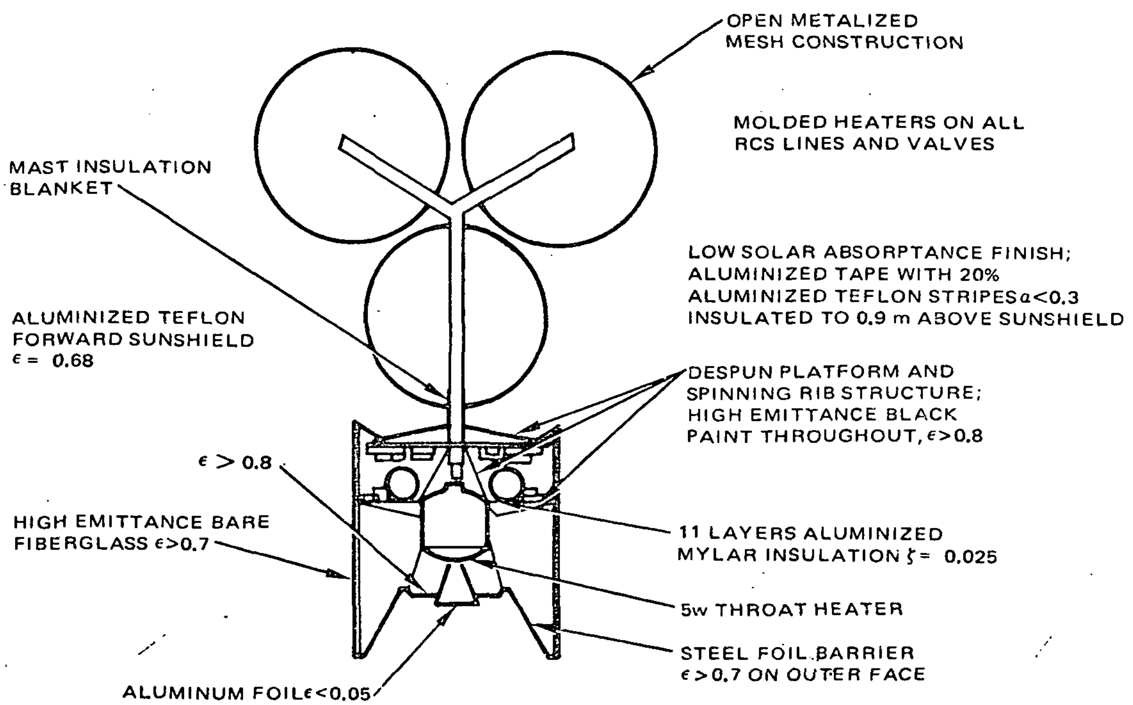
DEPLOYABLE S BAND HIGH GAIN ANTENNA

Ku BAND PARABOLIC REFLECTOR

Ku BAND EARTH COVERAGE HORNS

T, T&C VHF OMNI-ANTENNAS

ANTENNA SUBSYSTEM



THERMAL CONTROL PROVISIONS

20640-395(U)

4.2.3 User Satellites

The TDRS is compatible in frequency power level and sensitivity with the RF equipment located in the orbiting user satellites.

4.2.4 Launch Vehicle

The TDRS is electrically and mechanically compatible with the interface requirements of the Delta 2914 launch vehicle.

TABLE 4-6. TDRSS PCM TELEMETRY CHANNEL ASSIGNMENTS

Frame Word	Spinning	Despun
0	Frame sync	
1		Frame sync
2	Decoder 1 command verify(1)	
3		Decoder 1 command verify(1)
4	Decoder 2 command verify(1)	
5		Decoder 2 command verify(1)
6	Status word 6 Execute Separation/spin up Time of day Parallel relay	
7		Status word 7 Execute Encoder identifier
8	Status word 8 Sun/earth select Despin electronics Bypass relays	
9		Status word 9 Frequency synthesizer status
10	Attitude determination	
11		Status word 11 Frequency synthesizer status
12	Attitude determination	
13		Status word 13 Communications status

TABLE 4-6 (continued)

Frame Word	Spinning	Despun
14	Attitude determination	
15		Status word 15 Communications status
16	Telemetry calibration	
17		Telemetry calibration
18	Bus Current	
19		Bus voltage
20	Bus voltage	
21		Spare
22	Battery A voltage	
23		Antenna azimuth C/D***
24	Battery B voltage	
25		Antenna elevation C/D***
26	Battery pack 1 temperature	
27		BAPTA hub temperature 1/2*
28	Battery pack 2 temperature	
29		UHF command transmitter temperature A/B*
30	Charge/discharge A current	
31		UHF voice transmitter temperature A/B*
32	Charge/discharge B current	Aft shelf temperature (B)*
33		S band transmitter temperature A/B*
34	Battery pack 1 temperature	
35		Platform temperature 1/2*
36	Battery Pack 2 temperature	
37		Auxiliary battery voltage
38	Radial jet 1/2 temperature*	
39		K band transmitter temperature A/B*

TABLE 4-6 (continued)

Frame Word	Spinning	Despun
40	Axial jet 1/2 temperature*	
41		Heater bank A current
42	Spare	
43		Heater bank B current
44	Fuel tank 1/2 temperature*	
45		Heater bank C current
46	Hydrazine 1 pressure	
47		Heater bank D current
48	Hydrazine 2 pressure	
49		Spare
50	Motor torque command**	
51		Spare
52	BAPTA temperature 1/2*	
53		Spare
54	Despin position torque command**	
55		Spare
56	Solar panel temperature 1	
57		Spare
58	Solar panel temperature 2	
59		Spare
60	Apogee motor temperature 1/2*	
61		Spare
62	Sunshield temperature 1/2*	
63		Spare

*No. 1 or A input on encoder 1; No. 2 or B input on encoder 2.

**Both torque command signals are connected to each encoder via OR circuits, since only one despin control electronics unit is on at a time.

***Antenna C (west) on encoder 1; antenna D (east) on encoder 2. Digital output increase when antenna steers toward north or west.

TABLE 4-7. TDRSS COMMAND ASSIGNMENTS

Despun

COMMUNICATIONS

1. Frequency synthesizer A on
2. Frequency synthesizer B on
3. Frequency synthesizers off
4. Frequency synthesizer A output step for S-band transmit L. O.
5. Frequency synthesizer B output step for S-band transmit L. O.
6. Frequency synthesizer A output step for S-band receive L. O.
7. Frequency synthesizer output step for S-band receiver L. O.
8. K band receiver A on
9. K band receiver B on
10. K band receivers off
11. K band transmitter A on
12. K band transmitter B on
13. K band transmitters off
14. UHF command transmitter A on
15. UHF command transmitter B on
16. UHF command transmitters off
17. UHF power amplifier 1A on
18. UHF power amplifier 1A off
19. UHF power amplifier 2A on
20. UHF power amplifier 2A off
21. UHF power amplifier 3A on
22. UHF power amplifier 3A off
23. UHF power amplifier 4A on
24. UHF power amplifier 4A off
25. UHF power amplifier 5A on
26. UHF power amplifier 5A off
27. UHF power amplifier 6A on
28. UHF power amplifier 6A off
29. UHF power amplifier 7A on

TABLE 4-7 (continued

30.	UHF power amplifier 7A off
31.	UHF power amplifier 8 A on
32.	UHF power amplifier 8 A off
33.	UHF power amplifier 9 A on
34.	UHF power amplifier 9 A off
35.	UHF power amplifier 10 A on
36.	UHF power amplifier 10 A off
37.	UHF power amplifier 1B on
38.	UHF power amplifier 1B off
39.	UHF power amplifier 2B on
40.	UHF power amplifier 2B off
41.	UHF power amplifier 3B on
42.	UHF power amplifier 3B off
43.	UHF power amplifier 4B on
44.	UHF power amplifier 4B off
45.	UHF power amplifier 5B on
46.	UHF power amplifier 5B off
47.	UHF power amplifier 6B on
48.	UHF power amplifier 6B off
49.	UHF power amplifier 7B on
50.	UHF power amplifier 7B off
51.	UHF power amplifier 8 B on
52.	UHF power amplifier 8 B off
53.	UHF power amplifier 9 B on
54.	UHF power amplifier 9 B off
55.	UHF power amplifier 10 B on
56.	UHF power amplifier 10 B off
57.	UHF voice transmitter A on
58.	UHF voice transmitter B on
59.	UHF voice transmitters off
60.	VHF horizontal receiver A on
61.	VHF horizontal receiver B on

TABLE 4-7 (continued)

62.	VHF horizontal receivers off
63.	VHF vertical receiver A on
64.	VHF vertical receiver B on
65.	VHF vertical receivers off
66.	S band transmitter A on
67.	S band transmitter B on
68.	S band transmitters off
69.	S band power amplifier 1A on
70.	S band power amplifier 1A and 1B off
71.	S band power amplifier 2A on
72.	S band power amplifier 2A and 2B off
73.	S band power amplifier 3A on
74.	S band power amplifier 3A and 3B off
75.	S band power amplifier 4A on
76.	S band power amplifier 4A off
77.	S band power amplifier 1B on
78.	S band power amplifier 2B on
79.	S band power amplifier 3B on
80.	S band power amplifier 4B on
81.	S band receiver A on
82.	S band receiver B on
83.	S band receivers off
84.	Order wire receiver A on
88.	Order wire receiver B on
89.	Order wire receivers off
90.	S band transponder A on
91.	S band transponder B on
92.	S band transponder A and B off
TT&C	
93.	Telemetry encoder A on
94.	Telemetry encoder B on
95.	Telemetry encoders off

TABLE 4-7 (continued)

DEPLOYMENT MECHANISMS	
96.	Fire VHF/UHF antenna squib I
97.	Fire VHF/UHF antenna squib II
98.	Fire VHF/UHF antenna squib III
99.	Fire S band antenna squib I
100.	Fire S band antenna squib II
101.	Fire S band antenna squib III
102.	Fire K band antenna squib
103.	Fire nutation damper squib
104.	S band antenna positioner motors on
105.	Ku band antenna positioner motors on
106.	Antenna positioner power off
107.	Step S band antenna azimuth east
108.	Step S band antenna azimuth west
109.	Step S band antenna elevation north
110.	Step S band antenna elevation south
111.	Step Ku band antenna azimuth east
112.	Step Ku band antenna azimuth west
113.	Step Ku band antenna elevation north
114.	Step Ku band antenna elevation south
POWER SUBSYSTEM	
115.	Voltage limiters off
116.	Voltage limiter 1 on
117.	Voltage limiter 2 on
SPARES	
118-127	

TABLE 4-7 (continued)

Spinning	
REACTION CONTROL SUBSYSTEM AND APOGEE MOTOR	
1.	Axial jet 1
2.	Axial jet 2
3.	Axial jets 1 and 2
4.	Radial jet 1
5.	Radial jet 2
6.	Latching valve 1 open
7.	Latching valve 1 close
8.	Latching valve 2 open
9.	Latching valve 2 close
10.	Latching valve 3 open
11.	Latching valve 3 close
12.	Apogee motor squib 1 (decoder 1)
13.	Apogee motor squib 2 (decoder 2)
14.	Apogee motor heaters on
15.	Apogee motor heater 1 off
16.	Apogee motor heater 2 off
17.	Apogee motor heater 3 off
18.	Apogee motor heater 4 off
19.	Spinup jet heaters off
20.	Spinup jet heaters on
21.	Radial jet heater off
22.	Radial jet heater on
POWER SUBSYSTEM	
23.	Battery A charge on
24.	Battery B charge on
25.	Battery A and B charge off
26.	Trickle charge on
27.	Trickle charge battery A off

TABLE 4-7 (continued)

28.	Trickle charge battery B off
29.	Reconditioning discharge battery A on
30.	Reconditioning discharge battery B on
31.	Reconditioning charge batteries A and B off
32.	Set charge temperature limit 1
33.	Set charge temperature limit 2
34.	Set charge temperature limit 3
35.	Set charge temperature limit 4
36.	Thermal charge limit set override
37.	Voltage limiters off
38.	Voltage limiter 1 on
39.	Voltage limiter 2 on
40.	Voltage limiter 3 on
41.	Voltage limiter 4 on
DESPIN ELECTRONICS	
42.	BAPTA heater 1 on
43.	BAPTA heater 2 on
44.	Despin control electronics 1 on 2 off
45.	Despin control electronics 2 on 1 off
46.	Motor drive 1 on
47.	Motor drive 2 on
48.	Motor drive 1 off
49.	Motor drive 2 off
50.	Pseudo earth pulse select
51.	Sun despin reference select
52.	N earth sensor mode
53.	S earth sensor mode
54.	Pseudo psi despin reference
55.	Time correction step west
56.	Time correction step east

TABLE 4-7 (continued)

58.	Torque bias step negative
59.	Torque bias step positive
60.	Spinup sequencer enable
61.	Spinup sequencer off
TT&C	
62.	Telemetry encoder 1 PCM mode
63.	Telemetry encoder 2 PCM mode
64.	Telemetry encoder 1 on
65.	Telemetry encoder 1 off
66.	Telemetry encoder 2 on
67.	Telemetry encoder 2 off
68.	Telemetry encoder 1 FM mode
69.	Telemetry encoder 2 FM mode
70.	Telemetry transmitter A on
71.	Telemetry transmitter B on
72.	Telemetry transmitter A and B off
SPARES	
73 to 128	

4.3 SUBSYSTEM DESCRIPTION

The TDRS is comprised of nine major subsystems whose functional and performance characteristics are described in the following subsections.

4.3.1 Telecommunication Services

The TDRS telecommunication service system is designed to provide command and data relay capability for low and medium data rate unmanned user spacecraft and voice and data relay capabilities for manned user spacecraft.

The frequency bands employed for the TDRSS are shown in Subsection 3.1. The general performance requirements for the telecommunication services are listed in Table 4-9, and their implementation in the TDRS repeater/transmitter design is illustrated in Figure 4-4.

TABLE 4-8. OPERATIONAL SPACECRAFT RELIABILITY SUMMARY

Subsystem	5 Year Reliability Estimate
Communication and antenna positioning	0.889
Telemetry and command	0.900
ACS	0.955
Power	0.975
Harness	0.990
RCS	0.972
Total	0.717

Every active element in the repeater system is completely redundant. The repeater receives four different K band frequency channels from the ground station via two low gain K band horn antennas. These channels are shifted to an intermediate frequency, amplified, and distributed via a power divider.

The output of the six way power divider supplies the UHF transmitters, the S band transmitter, and the command subsystem. One additional signal, the reference pilot tone signal, is received by the K band receiver which phase locks its local oscillator to this reference. The local oscillator signal then drives the frequency synthesizer to provide coherent translation of all frequencies within the communication subsystem.

The signals from the VHF receivers, the S band receivers, and the S band order wire receivers are each shifted to a unique IF frequency before being summed in the 10 way power summer. The output of the power summer is fed into the K band transmitters. Telemetry and command signals are also routed through the K band transmitters. An S band transponder relays ranging data over an 8 MHz bandwidth ground link.

The VHF telemetry receivers are both on continuously during the life of the TDRS. This allows two redundant channels for command and control of the spacecraft in addition to a K band receiver.

Receiver characteristics are those of current state of the art equipment. Table 4-10 summarizes the receiver noise figures. Table 4-11 lists the masses of the repeater components, which total 54.3 kg.

There are six power modes possible corresponding to high or low UHF transmitter power and the S band transmitter high, low, or off. In addition to the unit power rating, a power summary for four modes is presented in Table 4-12.

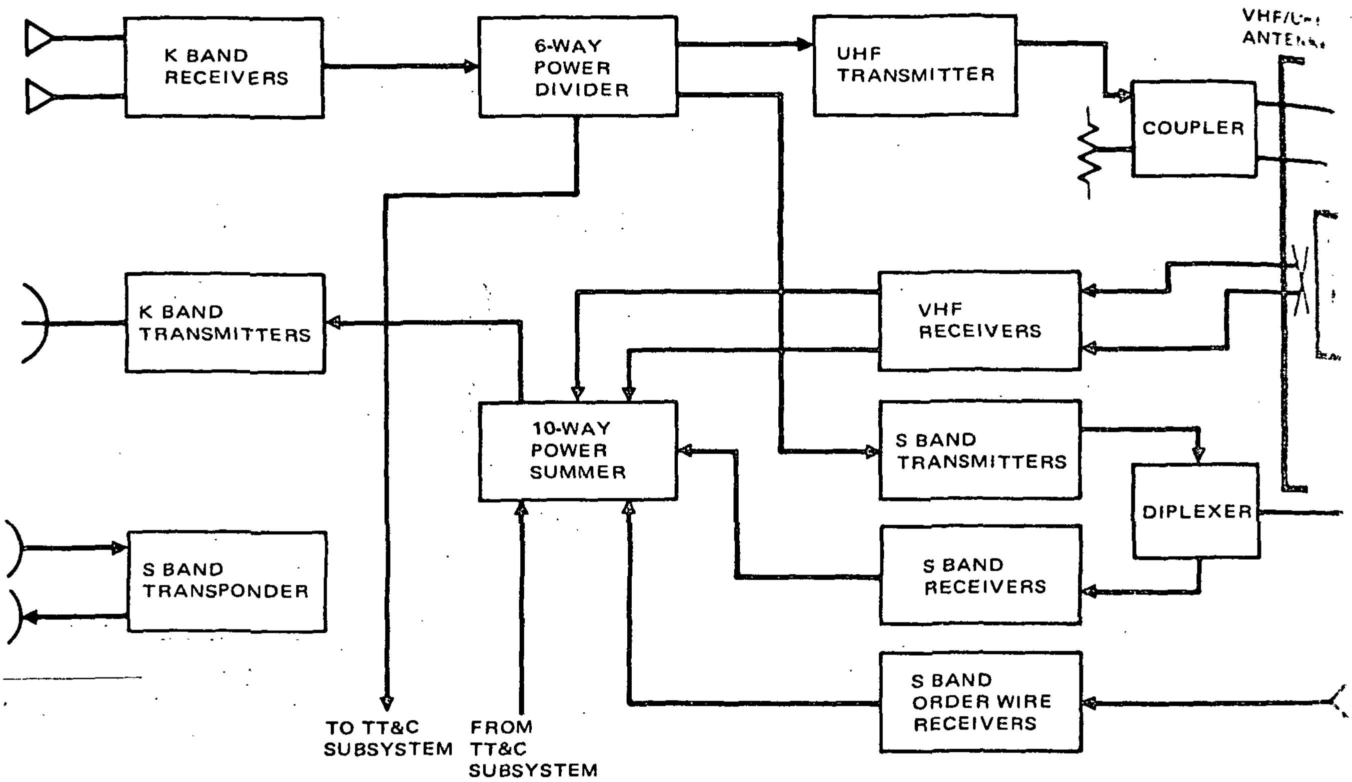


Figure 4-4. TDRS Spacecraft Repeater

TABLE 4-9. TDRS COMMUNICATION SUBSYSTEM

Low data rate service	
Forward link	
1) User command EIRP	30 dBw
2) Voice EIRP	30 dBw
Return link	
1) G/T	-16 dB/K within conical coverage of 0.454 radian
2) Linear amplification	
3) Separation of orthogonal linear polarized signal	
Medium data rate service	
Forward link EIRP at S band	41 dBw
Voice EIRPAT S band	47 dBw
Return link G/T at S band	2 dB/K (-13 dB/K for order wire)
Command service	
K_u band EIRP	51 dBw, 13.4 to 14.0 GHz
K_u band receiver sensitivity	-15 dB/K
General	
1) Repeater shall be of the frequency translation type	
2) Coherent frequency translations	
3) Order wire capability	
4) S band transponder for trilateral ranging	

TABLE 4-10. RECEIVER NOISE FIGURES

Receiver Band	Noise Figure, dB
VHF	3.9
S band	3.9
K band	9.0

TABLE 4-11. REPEATER MASS SUMMARY

	Mass, kg
K band receivers	2.6
K band transmitters	4.1
K band upconverter	0.8
Frequency synthesizers	8.2
S band transmitters	7.3
S band receivers	1.4
S band order wire receivers	1.9
S band transponder	7.6
UHF transmitters	17.2
VHF receivers	4.0
Total	55.1

TABLE 4-12. REPEATER POWER SUMMARY

		Telecommunication Mode			
		UHF High		UHF Low	
	Unit Power	S Band Low	S Band Off	S Band High	S Band Low
K band receiver	1.8	1.8	1.8	1.8	1.8
K band transmitter	31	31	31	31	31
K band upconverter	0.8	0.8	0.8	0.8	0.8
Frequency synthesizer	7.3	7.3	7.3	7.3	7.3
S band receiver	0.9	0.9	--	0.9	0.9
Order wire S band receiver	0.9	0.9	0.9	0.9	0.9
S band transmitter	21 or 88	21	--	88	20
S band transponder	21	21	21	21	21
UHF transmitter	141 or 280	280	280	141	141
VHF receiver	2.1	2.1	2.1	2.1	2.1

Transmitter power amplifier requirements for the low and high power ies of operation (see Table 4-13) have been established for calculated smission losses and antenna gains as listed in Tables 4-14, 4-15, and 6. A description of the antenna designs is presented in subsection 4.3.3.

3.2 Telemetry Tracking, and Command

The major tasks of the telemetry, tracking, and command subsystem re to 1) monitor and relay to a ground control station all spacecraft analog nd status data required for mission management and control, power management, repeater gain adjustments, etc.; and 3) provide satellite range information at any phase of its mission.

TABLE 4-13. TRANSMITTER POWER

Transmitter	Required Power Amplifier Output, watts
UHF	
Low power mode	71
High power mode	142
S band	
Low power mode	6.3
High power mode	23.5
K band saturation power	8
S band transponder	3.2

TABLE 4-14. UHF EIRP FOR LOW POWER MODE – COMMAND ONLY

Antenna gain	12.5 dB
Cable (20 feet) and connectors loss	-0.44 dB
Hybrid loss	-0.16 dB
Low pass filter loss	-0.4 dB
Required RF power (summer output)	18.5 dBw (71 watts)
EIRP	30.0 dBw

TABLE 4-15. S BAND EIRP

	Low Power	High Power
Antenna gain, dB	36.0	36.0
Cable loss, dB	-1.2	-1.2
Diplexer loss, dB	-0.8	-0.8
Isolator loss, dB	-0.2	-0.2
Summer loss, dB	--	-0.25
Switch loss, dB	-0.2	--
RF power, minimum, dBw	8.0	13.7
EIRP, dBw	41.4	47.0

TABLE 4-16. K BAND EIRP

Antenna gain	44.0 dB
Waveguide loss	-1.0 dB
Rotary joints loss	-0.5 dB
Switch loss	-0.2 dB
Filter loss	-0.3 dB
Transmitter power	9.0 dBw
	51.0 dBw

Telemetry, tracking, and command performance characteristics are listed in Table 4-17. A block diagram of the TT&C subsystem is illustrated in Figure 4-5. All units are fully redundant and cross-strapped. A command transmission consists of a microwave carrier modulated by a sequence of tones at three discrete frequencies, designated 1, 0, and execute. The tones

TABLE 4-17. TELEMETRY AND COMMAND PERFORMANCE CHARACTERISTICS

Parameter	Characteristics
TELEMETRY – INTELSAT IV TYPE	
M Mode	
Word length	8 bits
Frame length	64 words
Analog	48 words
Digital words	16
Bit rate	1000 bits/sec
Code type output	Manchester
M Mode (attitude data)	
Subcarrier frequency	14. 5 kHz
Data type	Real time pulses
Modulation	FM
Data transmitted	1) Sun pulses 2) North earth pulses 3) South earth pulses 4) Execute receipt
COMMAND – INTELSAT IV TYPE, MODIFIED	
Tones	1, 0, and execute
Input signal	FSK/AM
Bit rate	128 bits/sec
Command capacity,	255 maximum
Command verification via	Telemetry
Command execution	Real time
Execution synchronization	Sun or earth pulses
Maximum command rate	Approximately 4 per second

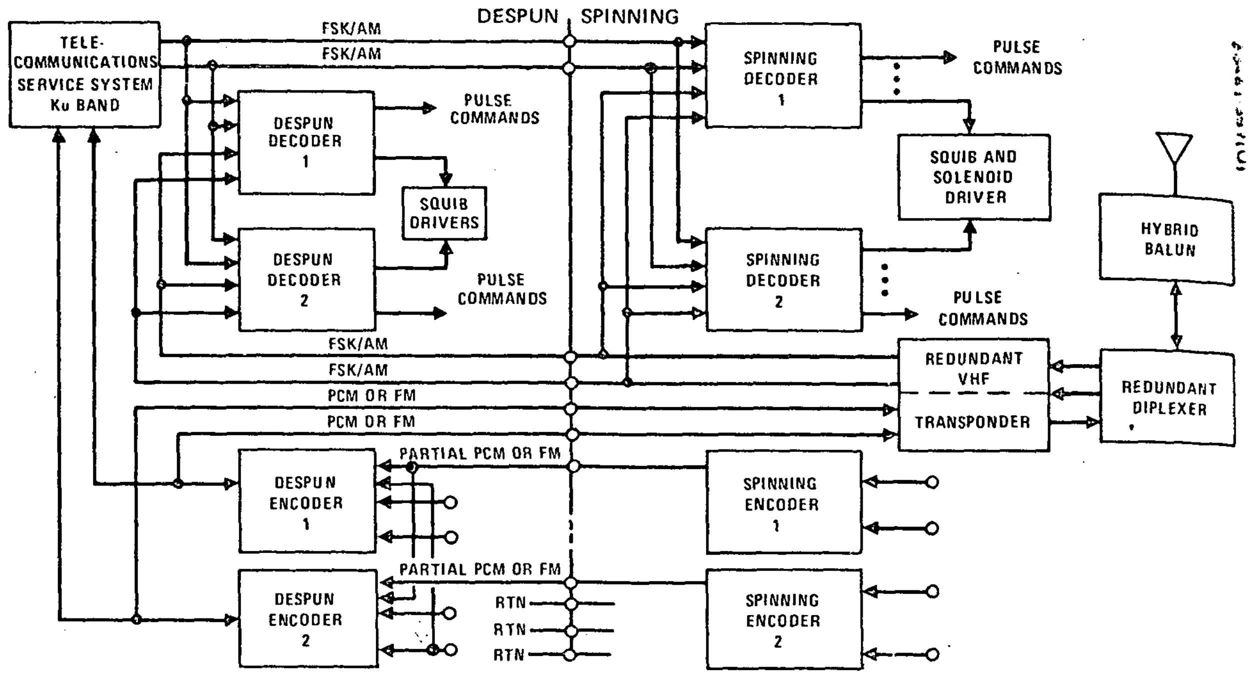


Figure 4-5. Telemetry and Command Subsystem

COMMAND GENERATOR CONTROL	FUNCTION PERFORMED	TONE	CODE	DURATION
ACTUATE XMIT				
	INTRODUCTION (CLEAR)	C	16 BITS	258 ms
		1	1 BIT	
	DECODER ADDRESS	0 AND 1	6 BITS	
		1	2 BITS	
	COMMAND	0 AND 1	8 BITS	
READ DECODER REGISTERS	COMMAND VERIFICATION VIA TELEMETRY			
ACTUATE EXECUTE				
	COMMAND EXECUTE	EXECUTE TONE	AS REQUIRED	VARIABLE TIME (40 ms FOR STANDAR: SINGLE COMMAND)
ACTUATE CLEAR				
	CLEAR THE DECODER REGISTERS	0	16 BITS	133 ms
		1	1 BIT	

Figure 4-6. Command Format

... amplitude modulated. The demodulated output of the ku band receiver ... the VHF command receiver drive both the despun and spinning decoders. ... selection of the executing decoder is by unique decoder address. Com... verification is provided by telemetry readout of the command register ...ore sending the exeuction tone (Figure 4-6).

A functional description of the spinning and despun decoder is shown ... Figure 4-7.

Two receiver sequencers sample the two VHF and the two Ku receiver ...puts to select one which has a suitable output signal. The output of the ...st stage of each filter goes to the AM detector where the two signals are ...mmed and the composite signal is full-wave rectified and fed to a clock ...ise generator which contains a narrow bandpass filter tuned to the 128 Hz ... rate. The output of the 128 Hz bandpass filter is the demodulated AM, ... 128 Hz sine wave with an amplitude proportional to the signal strength of ...e received AM-FSK signal. The 128 Hz sine wave is fed to a hard limiter ... the squelch circuit. The squelch circuit puts out a signal to enable the ...ecoder processing when the input signal exceeds a preset threshold level. ...he 128 Hz sine wave is also fed to the clock pulse generator which generates ...e clock signals to drive the remainder of the demodulator.

In addition to its command outputs, each decoder provides readout of ...ts register (command verification) and the envelope of all execute tone ...ulses.

A spinning squib and solenoid driver unit generates suitable signals for firing the BAPTA clamp release, apogee motor squibs, and for energiz...ng the latching valve and thruster solenoids. A despun squib driver unit generates signals for antenna deployment. There are four squib drivers and ten solenoid drivers.

Signal and word format of the demodulated command from a receiver consists of a sequence of 1, 0, and execute tone pulses. These are arranged as shown in Figure 4-6. For convenience, the 1 and 0 pulses will be referred to as bits, as they convey binary information to the decoder logic circuit. The introduction portion of the command word consists of at least 16 0-bits followed by a 1 bit. This resets the decoder registers and logic; the decoder is then able to process the remainder of the command word. The next ... bits comprise the address portion of the command word. The first 6 provide the coding for digital addresses. The address words are separated by a minimum Hamming distance of 2, so that a signal error in the transmission or reception of a decoder address will not result in the successful addressing of a wrong decoder. The last two bits are both 1's, which ensures that the introduction sequence will never be repeated within the command word.

The command itself consists of 8 bits. The 8 command bits are entered into a storage register for verification via telemetry. Once a command

word is entered into storage; further processing of data bits is inhibited and an introduction format must be sent to clear the register. Upon receipt of the execute tone, a coincident pulse will occur on the decoder output line corresponding to the stored command. Execute tone pulses can be sent for as long or as frequently as required. After the command has been executed, the commanding ground station resets and clears the decoder by repeating the introduction.

The telemetry subsystem, in the primary mode of operation, provides two independent channels (Figure 4-5) transmitting on separate carrier frequencies with separate telemetry encoders for each channel. Two modes of data processing are used: PCM and FM real time.

The PCM mode is used for all attitude, thermal, power, and status information, including command verification. In the PCM mode, the spinning encoder receives, processes, and formats data originating on the spinning portion of the satellite. The output, which is connected across the spinning/despun interface via slip rings, is an 8 kHz biphase waveform from which a despun encoder recovers the nonreturn to zero (NRZ-L) bit stream and derives a coherent clock. The despun encoder gathers and processes data originating in the despun portion. It alternates its bit stream word-by-word with the spinning encoder bit stream, then converts the composite NRZ-L bit stream to a Manchester code format. The converted stream is used for phase modulating a Ku band carrier within the telecommunication repeater on the despun side and modulates the backup VHF transmitter on the spinning side.

The FM real time mode is used for real time attitude pulses (sun sensor pulses, earth sensor pulses, platform index pulses, and command execute pulses). The occurrence of a pulse coherently switches the frequency, of an IRIG channel 13 subcarrier oscillator from its pilot tone to a different frequency, depending on the kind of pulse present. The output is connected via a slip ring to the despun encoder, the output of which phase modulates the Ku and VHF telemetry transmitters.

The functional design of the spinning encoder and the despun encoder is illustrated in the block diagrams, Figures 4-8 and 4-9.

Weight, power, and dimensional data for components of the telemetry subsystem are listed in Table 4-18.

4.3.3 Antennas

The TDRS antenna subsystem consists of eight antennas as shown in Figure 4-10. The antenna mechanical designs are compatible with the stowage volume within the Delta 2914 payload fairing and are dimensioned to sustain quasi-static loads up to 30 g and random vibration of 147 in./sec^2 rms.

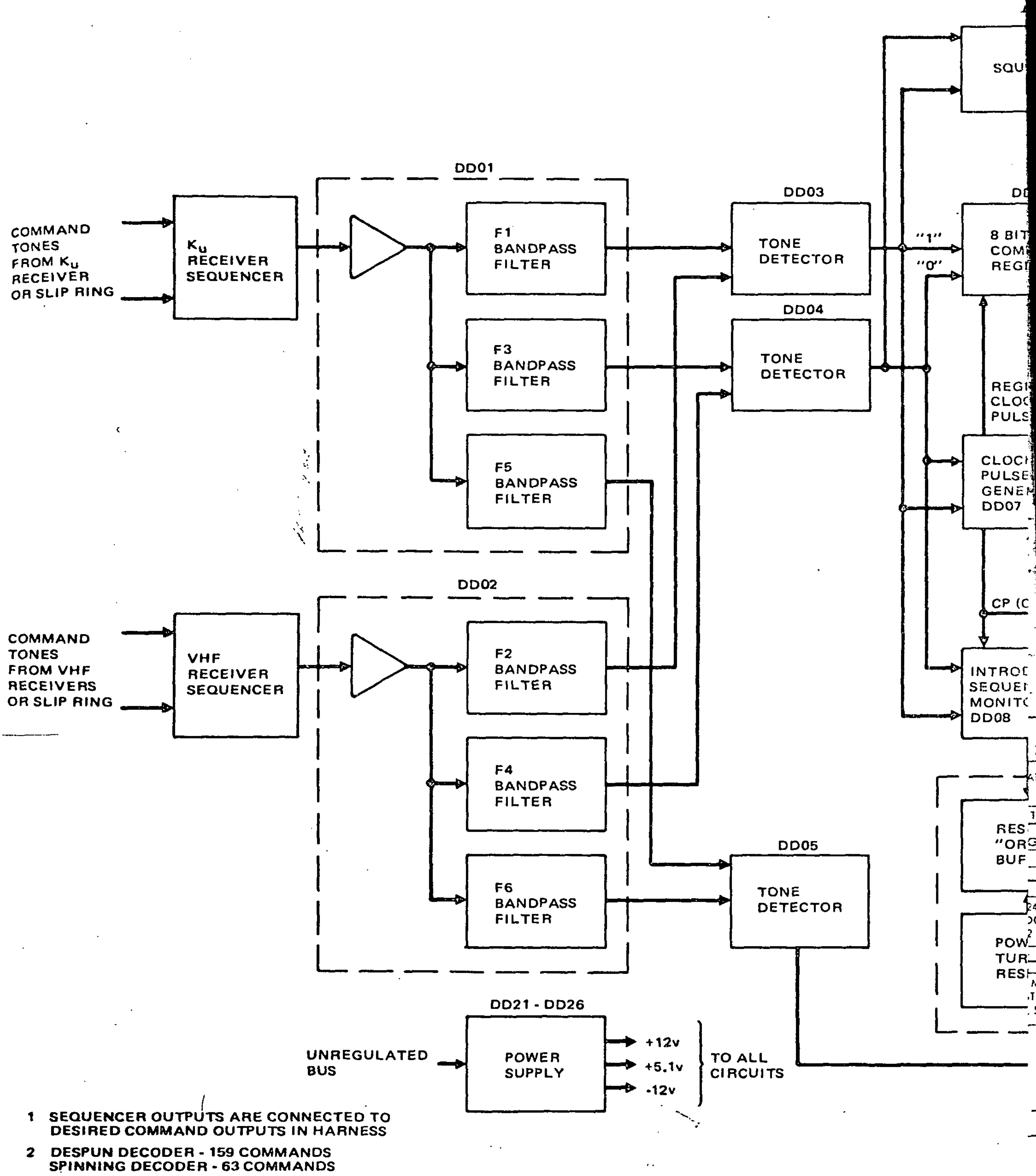
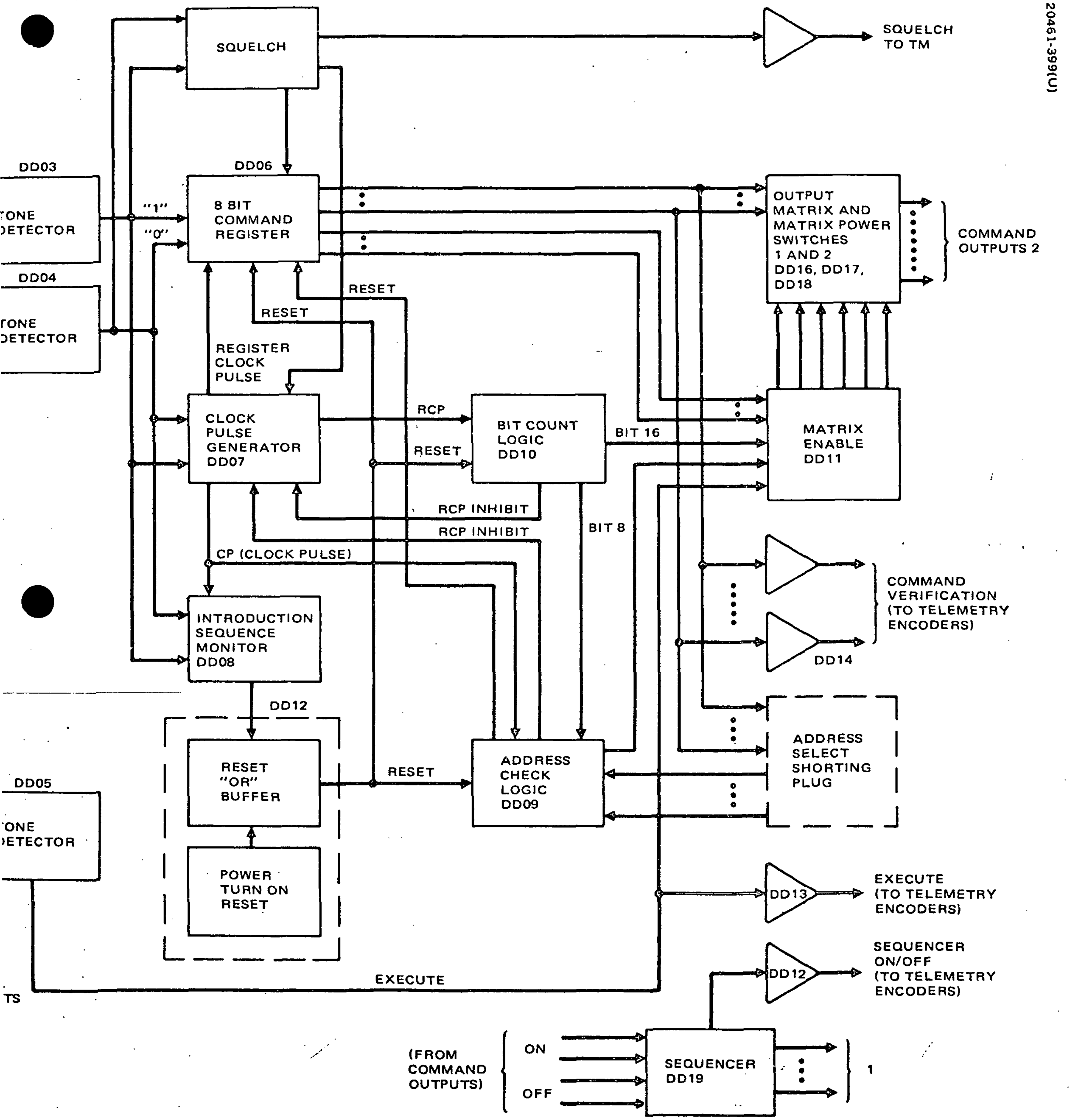


Figure 4-7. Despun or Spinning Decoder Block Diagram


SQUELCH
SQUELCH TO TM
DD03
TONE DETECTOR
DD04
TONE DETECTOR
DD05
ONE DETECTOR
DD06
8 BIT COMMAND REGISTER
"1"
"0"
RESET
RESET
REGISTER CLOCK PULSE
CLOCK PULSE GENERATOR DD07
RCP
RESET
BIT COUNT LOGIC DD10
BIT 16
BIT 8
RCP INHIBIT
RCP INHIBIT
CP (CLOCK PULSE)
INTRODUCTION SEQUENCE MONITOR DD08
DD12
RESET "OR" BUFFER
POWER TURN ON RESET
RESET
ADDRESS CHECK LOGIC DD09
OUTPUT MATRIX AND MATRIX POWER SWITCHES 1 AND 2 DD16, DD17, DD18
COMMAND OUTPUTS 2
MATRIX ENABLE DD11
COMMAND VERIFICATION (TO TELEMETRY ENCODERS)
DD14
ADDRESS SELECT SHORTING PLUG
DD13
EXECUTE (TO TELEMETRY ENCODERS)
DD12
SEQUENCER ON/OFF (TO TELEMETRY ENCODERS)
EXECUTE
TS
(FROM COMMAND OUTPUTS)
ON
OFF
SEQUENCER DD19
1
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gram

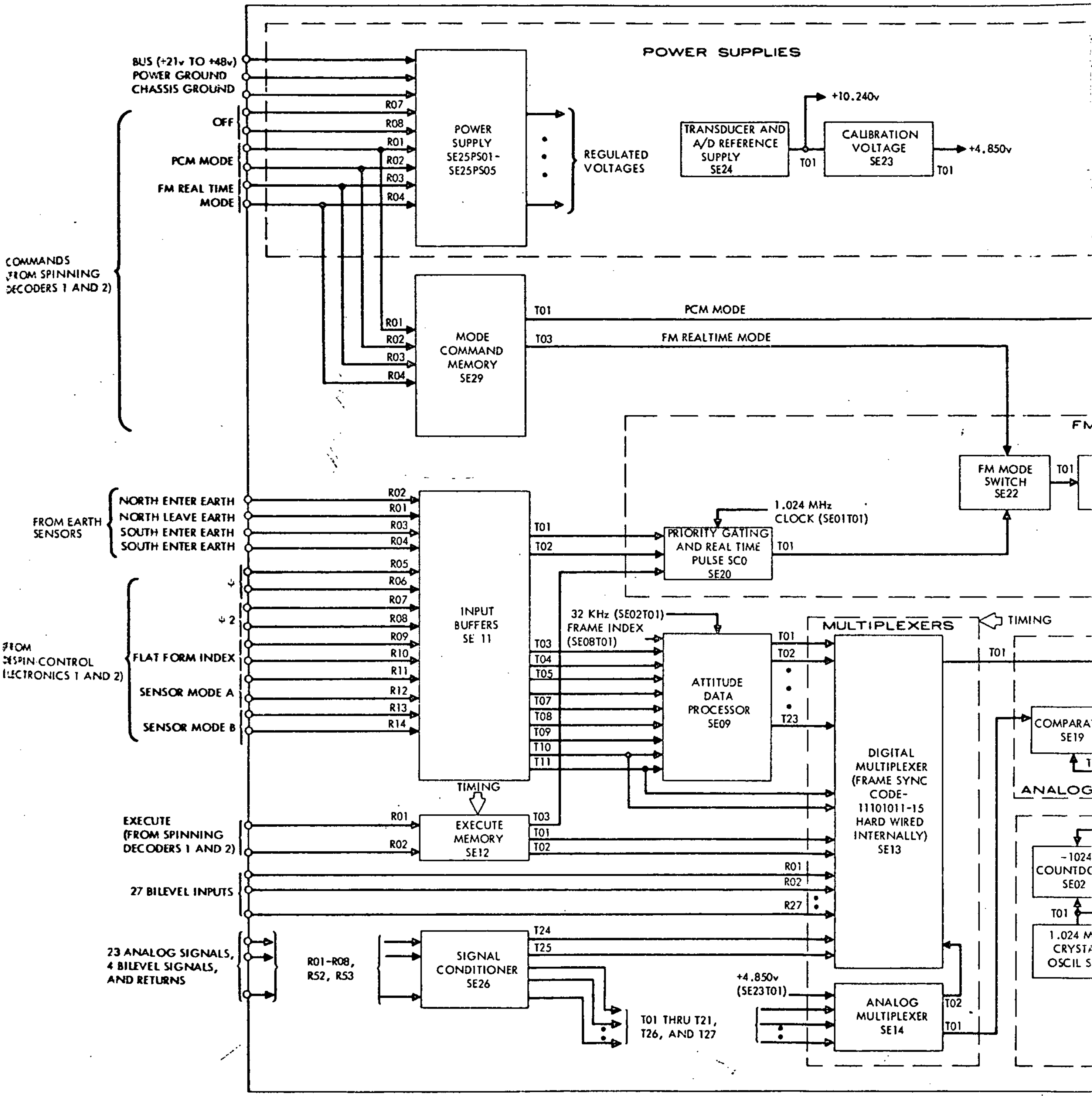

Figure 4-8. Spinning Encoder Block Diagram

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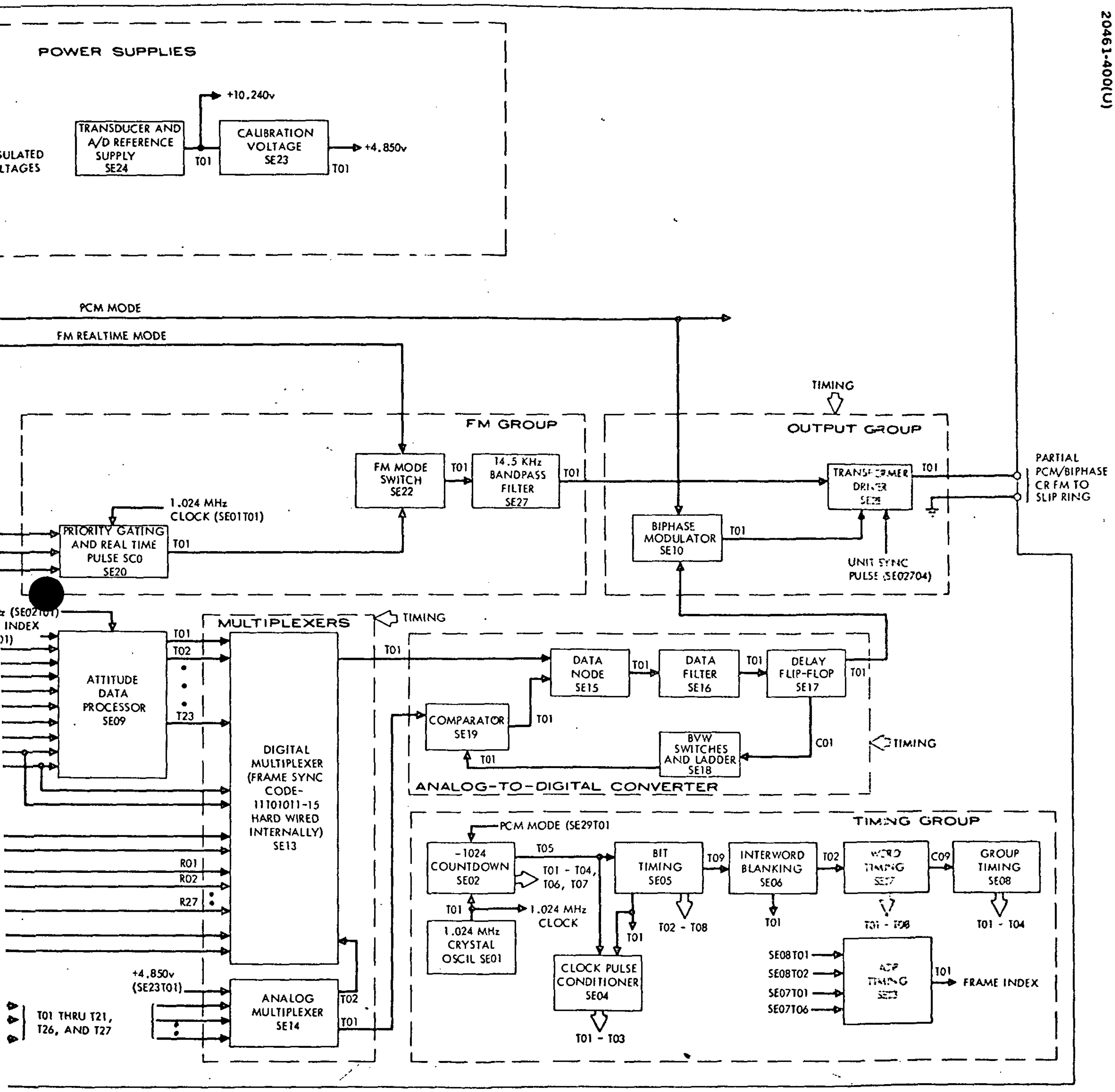


POWER SUPPLIES
+10.240v
TRANSDUCER AND A/D REFERENCE SUPPLY SE24
CALIBRATION VOLTAGE SE23
+4.850v
T01
ULATED
LTAGES
PCM MODE
FM REALTIME MODE
TIMING
FM GROUP
OUTPUT GROUP
FM MODE SWITCH SE22
14.5 KHz BANDPASS FILTER SE27
1.024 MHz CLOCK (SE01T01)
PRIORITY GATING AND REAL TIME PULSE SCO SE20
BIPHASE MODULATOR SE10
PARTIAL PCM/BIPHASE CR FM TO SLIP RING
UNIT SYNC PULSE (SE02704)
INDEX
MULTIPLEXERS
ATTITUDE DATA PROCESSOR SE09
T01
T02
T23
DIGITAL MULTIPLEXER (FRAME SYNC CODE- 11101011-15 HARD WIRED INTERNALLY) SE13
R01
R02
R27
+4.850v (SE23T01)
ANALOG MULTIPLEXER SE14
T01 THRU T21, T26, AND T27
DATA NODE SE15
DATA FILTER SE16
DELAY FLIP-FLOP SE17
COMPARATOR SE19
BVW SWITCHES AND LADDER SE18
C01
ANALOG-TO-DIGITAL CONVERTER
TIMING GROUP
PCM MODE (SE29T01)
-1024 COUNTDOWN SE02
T05
T01 - T04, T06, T07
1.024 MHz CLOCK
1.024 MHz CRYSTAL OSCIL SE01
BIT TIMING SE05
T09
INTERWORD BLANKING SE06
C09
GROUP TIMING SE08
T02 - T08
T01 - T04
CLOCK PULSE CONDITIONER SE04
T01 - T03
SE08T01
SE08T02
SE07T01
SE07T06
FRAME INDEX

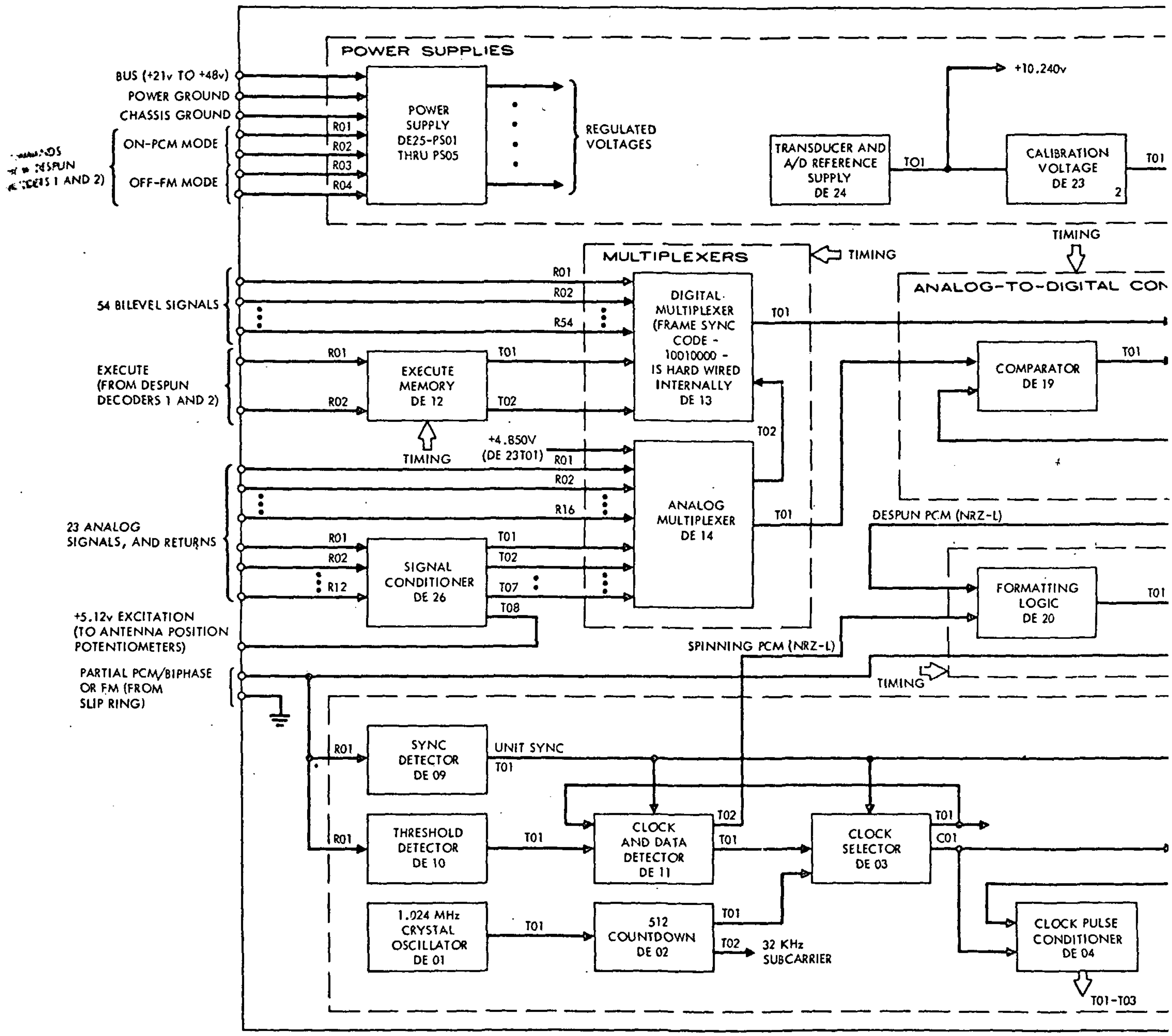
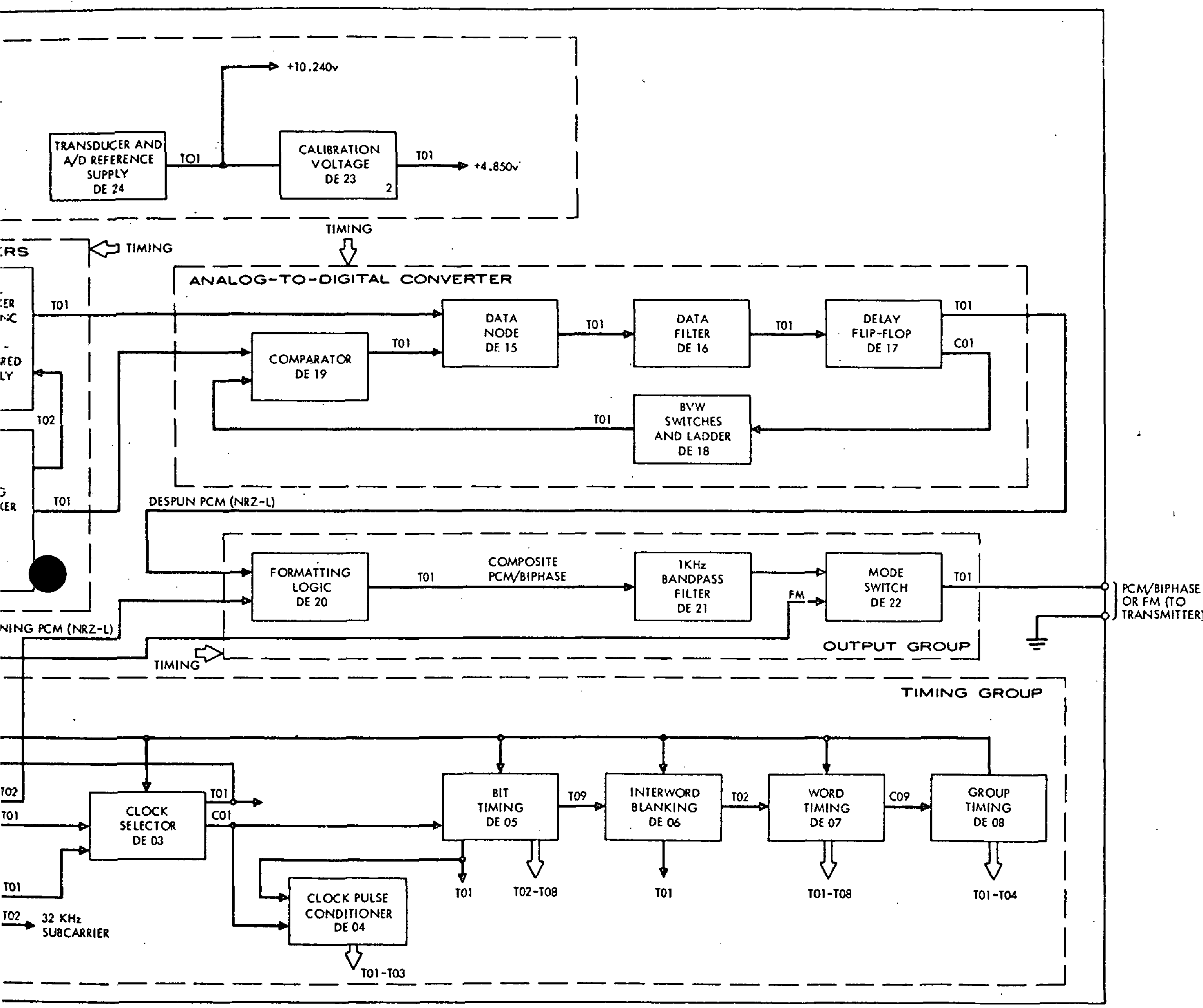


Figure 4-9. Despun Encoder Block Diagram



+10.240v
TRANSDUCER AND A/D REFERENCE SUPPLY DE 24
T01
CALIBRATION VOLTAGE DE 23
2
T01
+4.850v
TIMING
:RS
TIMING
ANALOG-TO-DIGITAL CONVERTER
T01
DATA NODE DE 15
T01
DATA FILTER DE 16
T01
DELAY FLIP-FLOP DE 17
T01
C01
COMPARATOR DE 19
T01
BVW SWITCHES AND LADDER DE 18
T01
T02
T01
DESPUN PCM (NRZ-L)
FORMATTING LOGIC DE 20
T01
COMPOSITE PCM/BIPHASE
1KHz BANDPASS FILTER DE 21
FM
MODE SWITCH DE 22
T01
PCM/BIPHASE OR FM (TO TRANSMITTER)
NING PCM (NRZ-L)
TIMING
OUTPUT GROUP
TIMING GROUP
T02
T01
CLOCK SELECTOR DE 03
T01
C01
T01
T02
32 KHz SUBCARRIER
BIT TIMING DE 05
T09
INTERWORD BLANKING DE 06
T02
WORD TIMING DE 07
C09
GROUP TIMING DE 08
CLOCK PULSE CONDITIONER DE 04
T01
T02-T08
T01
T01-T08
T01-T04
T01-T03

20461-401(U)

TABLE 4-18. TELEMETRY, TRACKING, AND COMMAND COMPONENT PHYSICAL CHARACTERISTICS

Unit	Number per Spacecraft	Mass per Spacecraft kg	28 Volt Bus		Size, cm			Program Identification
			Power Per Unit, watts	Spacecraft Standby Power, watts	Width	Length	Height	
Despun								
Decoder	2	2.7	0.9/1.8 (3)	1.8	14.7	22.6 (1)	6.9	HS 312
Encoder	2	3.2	4.0		14.7	22.6 (1)	6.9	HS 312 M.C.
Squib driver	1	0.5	--	--	14.7	15.2	3.6	
Dual transponder	1	3.1	21/9.6 (2)	9.6	18.5	43.2	5.1	
Diplexer	1	0.5	--	--	8.9	19.1	10.0	HS 333
Spun								
Decoder	2	2.7	0.9/1.8 (2)	1.8	14.7	31.0 (1)	6.9	HS 312
Encoder	2	4.0	5.0	5.0	14.7	31.0 (1)	6.9	HS 312 Mod
Solenoid and squib driver	1	0.9	--	--	14.7	34.3	3.6	HS 320
Latching valve - heater driver	1	0.5	--	--	6.6	8.9	7.4	--

Notes:

(1) Stackable units

(2) High power/low power

(3) Standby/execute

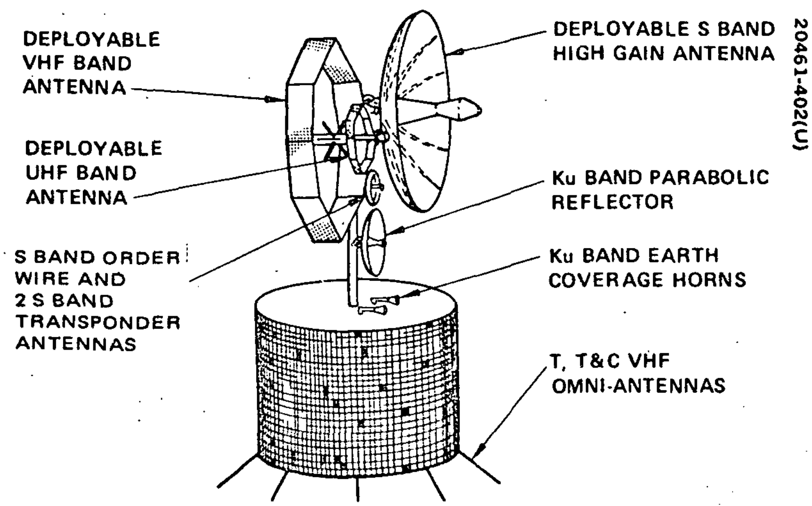


Figure 4-10. TDRS Antenna Subsystem

3.1 VHF/UHF Deployable Antenna

The VHF/UHF deployable antenna is made up of two stacked short backfire antennas as shown in Figure 4-11. The short backfire antenna consists of two plane reflectors spaced approximately a half wavelength apart and a feed placed between them. The VHF antenna reflector is cupped to form a cylindrical cavity. The feed is a crossed dipole centered between the two reflectors. The back reflector of the VHF antenna is 1.7 wavelengths in diameters.

The coaxial cable feed lines are 0.635 cm Alumispline manufactured by Times Wire and Cable Company. Stripline hybrids and baluns are located at the base of the antenna post to generate two orthogonal senses of linear polarization at VHF and circular polarization at UHF. The cables for the UHF antenna are routed down inside the VHF center post feed support.

The primary VHF reflective surface consists of a 1.27 cm grid Chromel-R wire mesh supported by eight 3.82 cm diameter tubular aluminum ribs. A secondary mesh surface, or "fence," is shaped and supported by ribs hinged at the outer tip of each primary rib.

The UHF antenna primary ribs are constructed from 1.91 cm diameter AL tubes with the wall thickness tapering from 204 microns at the root to a constant wall thickness of 102 microns. The ribs are highly polished to provide the necessary thermal control.

A cone/cylinder provides the central support for stacking the dual antenna cavities. This central structure consists of five portions: three cones and two cylinders. Three portions, a hub, lower cone/cylinder, and an upper cone/cylinder, are assembled by screws which allow the structure to be disassembled for access to each deployment system, RF feed lines, and microwave components within the cone. The center structure is topped off with a dielectric structure extending up to the top of the folded ribs. The function of this member provides an attachment structure for attaching the antenna to the spacecraft; it also provides a base to restrain the ribs in the stowed condition. The structure loads are primarily reacted at the antenna base and tip through tiedown locks to spacecraft structure.

The mechanism used to deploy the VHF antenna ribs is identical to that which will be described for the S band antenna. A second mechanism used to deploy the UHF ribs has a kinematic action identical to the VHF deployment system with the exception that it uses a cable drive to move deployment carrier along a recirculating ball spline from the stowed position to the deployed location. The VHF ribs are partially deployed before the UHF ribs start to rotate from their stowed positions.

Details of the dual frequency antenna design have been generated by Radiation Incorporated. The RF performance parameters are listed in Table 4-19. The mass of the antenna is calculated to be 7.95 kg.

TABLE 4-19. VHF-UHF ANTENNA PERFORMANCE

Frequency band, MHz	136 to 138	400.5 to 401.5
Aperture diameter, meters	3.9	1.3
Aperture gain,* dB	14.0	15.0
Reflector surface loss, dB	0.01	0.02
Reflector mesh I^2R loss, dB	0.02	0.08
Hybrid loss, cm rms	(0.635 cm) θ	(0.635 cm) 0.16 dB
Coaxial cable loss, dB	0.03	0.09
VSWR loss (1.3:1), dB	0.08	0.08
Total loss, dB	0.14	0.43
Antenna peak gain, dB	13.86	14.57
Antenna FOV gain, db (±13°)	11.86	12.50
Polarization sense	(Linear Horizontal and Vertical)	(Circular Polarization)

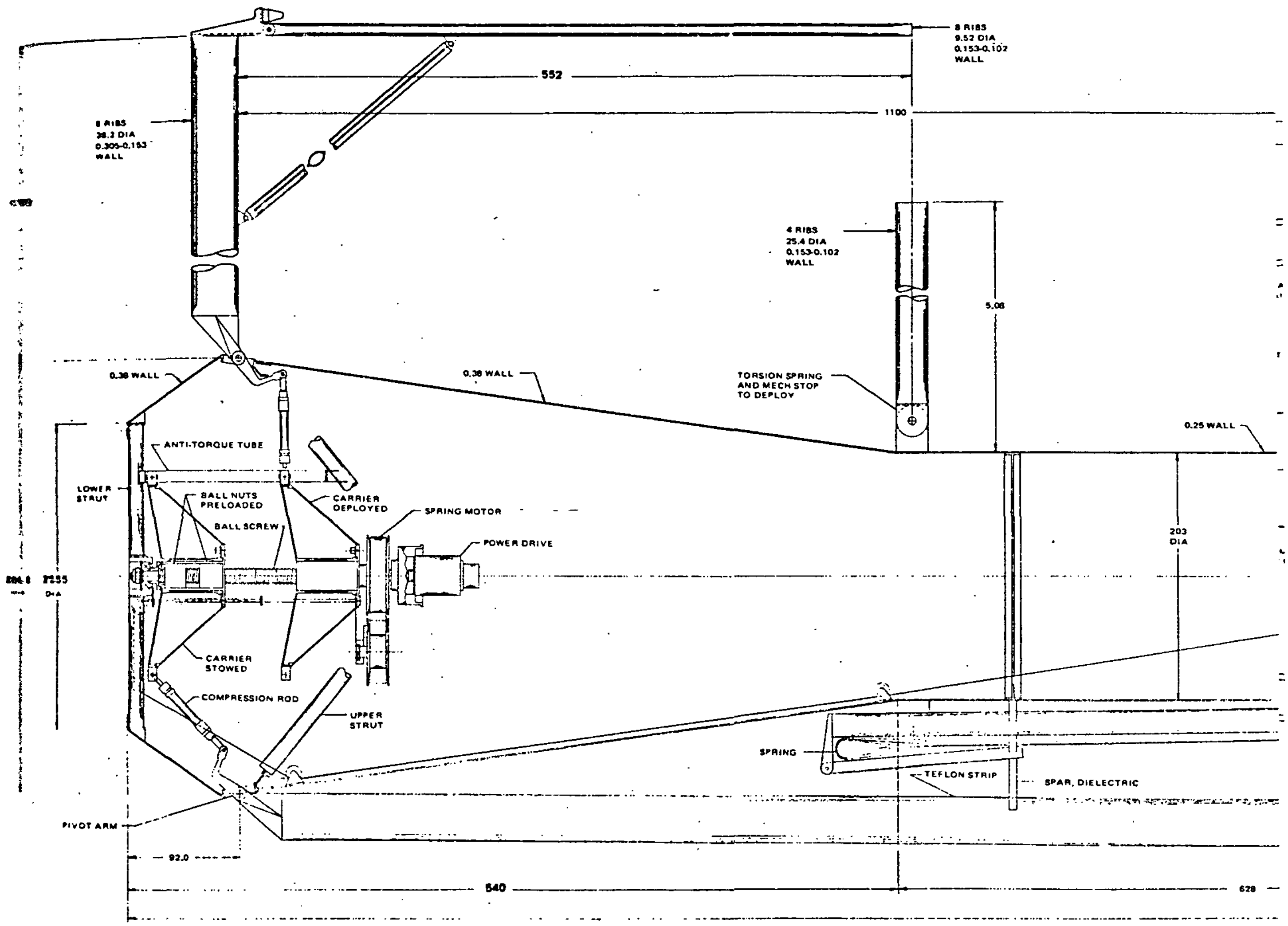
*L. R. Dog, Backfire Yagi Antenna Measurements.

4.3.3.2 S Band High Gain Antenna

The S band high gain antenna consists of a 3.82 meter diameter, deployable, parabolic reflector and coaxial cavity feed, all mounted on a two-axis positioner for beam pointing. The parabolic reflector is a rigid rib and mesh device with an f/d ratio of 0.4. The feed consists of a round coaxial cavity, fed by a polarizing network consisting of a quadrature hybrid and two baluns feeding four probes mounted in the cavity. The quadrature hybrid provides operation with two orthogonal senses of circular polarization.

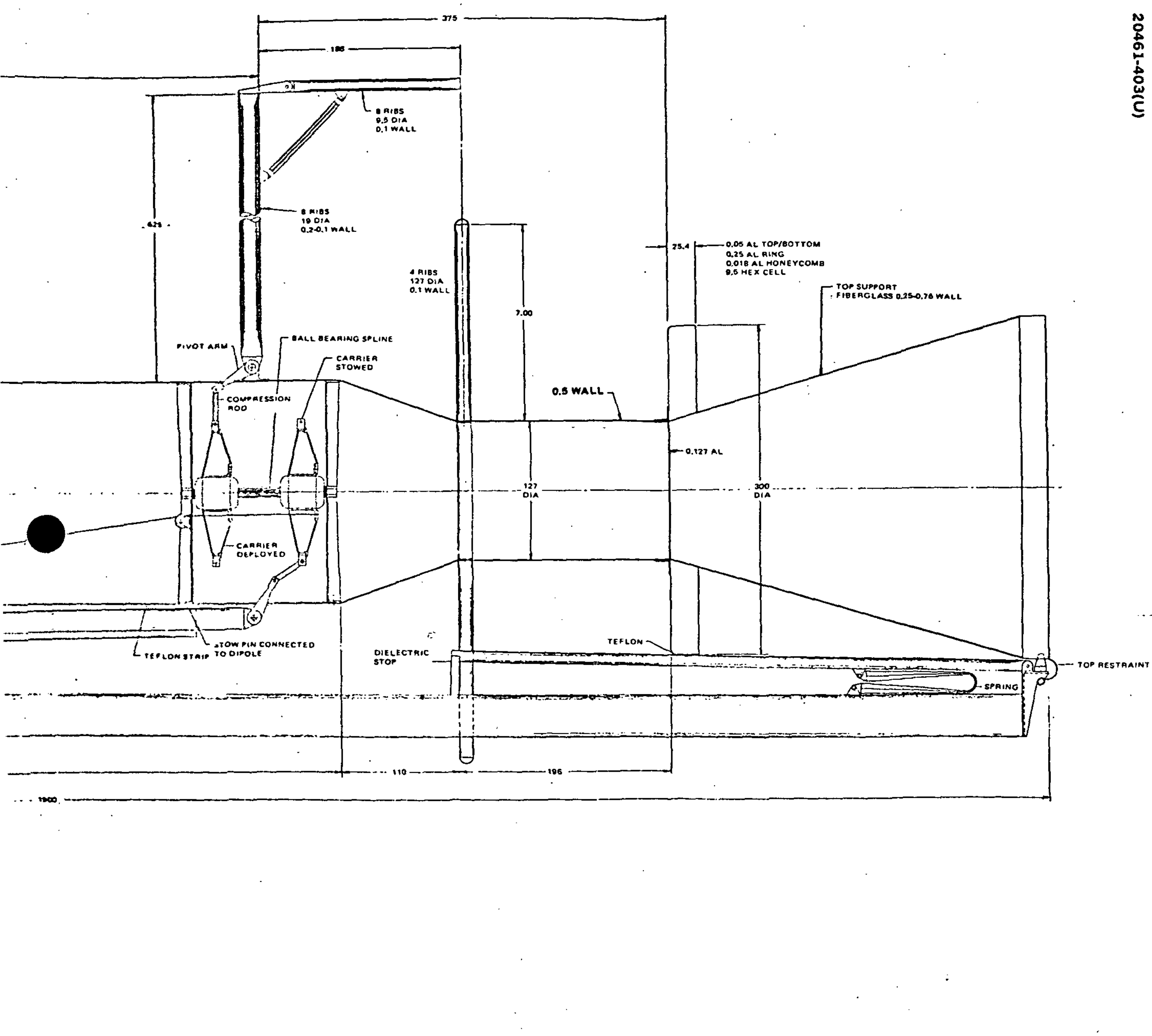
Figure 4-12 illustrates the S band antenna reflector in its stowed configuration. An aluminum feed support cone forms the central structure to which all components are attached. The antenna ties to the primary spacecraft structure at its base and tip in the stowed position.

The parabolic reflector is formed by 12 rigid ribs of 3.82 cm thin wall aluminum tubes which support and contour an elastic mesh surface. The deployed antenna resonance exceeds the 4 Hz requirement imposed by



DIMENSIONS IN MILLIMETERS

Figure 4-11. Dual Frequency Antenna Layout



375
186
8 RIBS
9.5 DIA
0.1 WALL
8 RIBS
19 DIA
0.2-0.1 WALL
625
4 RIBS
127 DIA
0.1 WALL
7.00
25.4
0.05 AL TOP/BOTTOM
0.25 AL RING
0.018 AL HONEYCOMB
9.5 HEX CELL
TOP SUPPORT
FIBERGLASS 0.25-0.76 WALL
PIVOT ARM
BALL BEARING SPLINE
CARRIER
STOWED
COMPRESSION
ROD
0.5 WALL
0.127 AL
127
DIA
300
DIA
CARRIER
DEPLOYED
STOW PIN CONNECTED
TO DIPOLE
TEFLON STRIP
DIELECTRIC
STOP
TEFLON
TOP RESTRAINT
SPRING
110
196
1900

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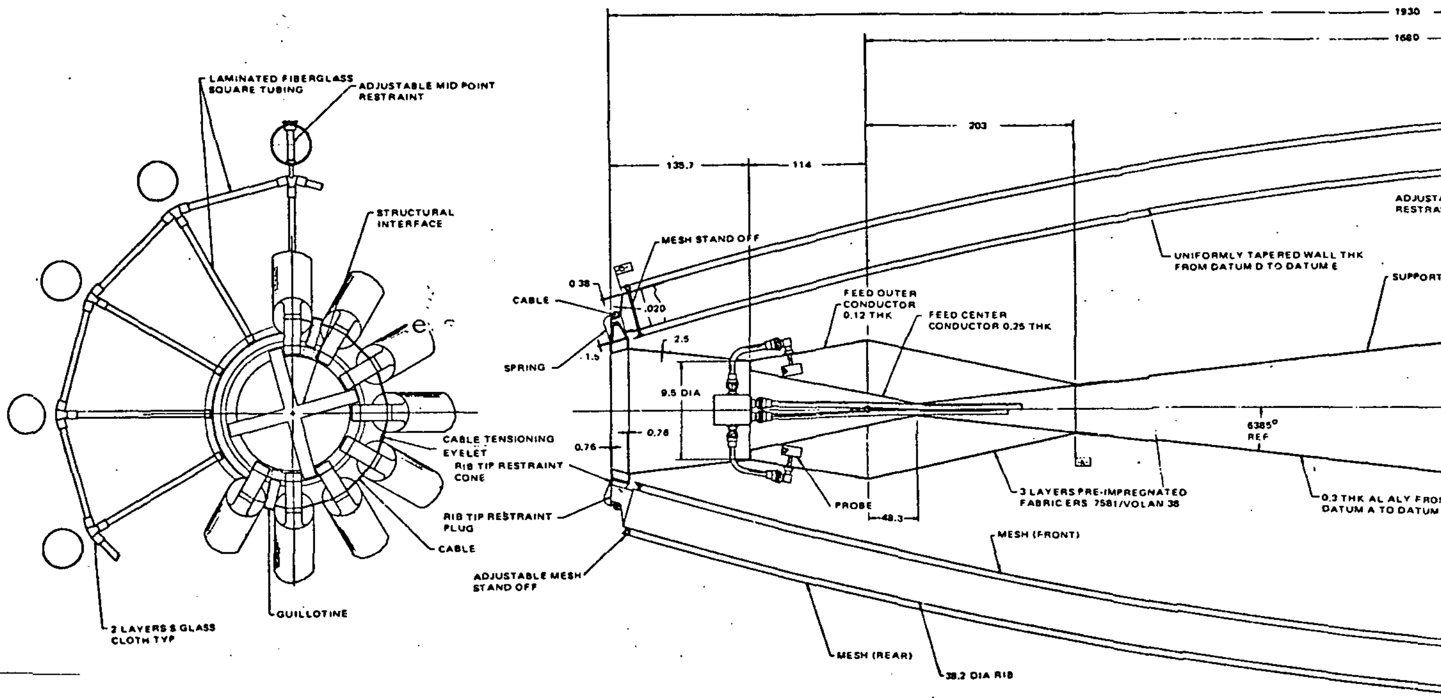
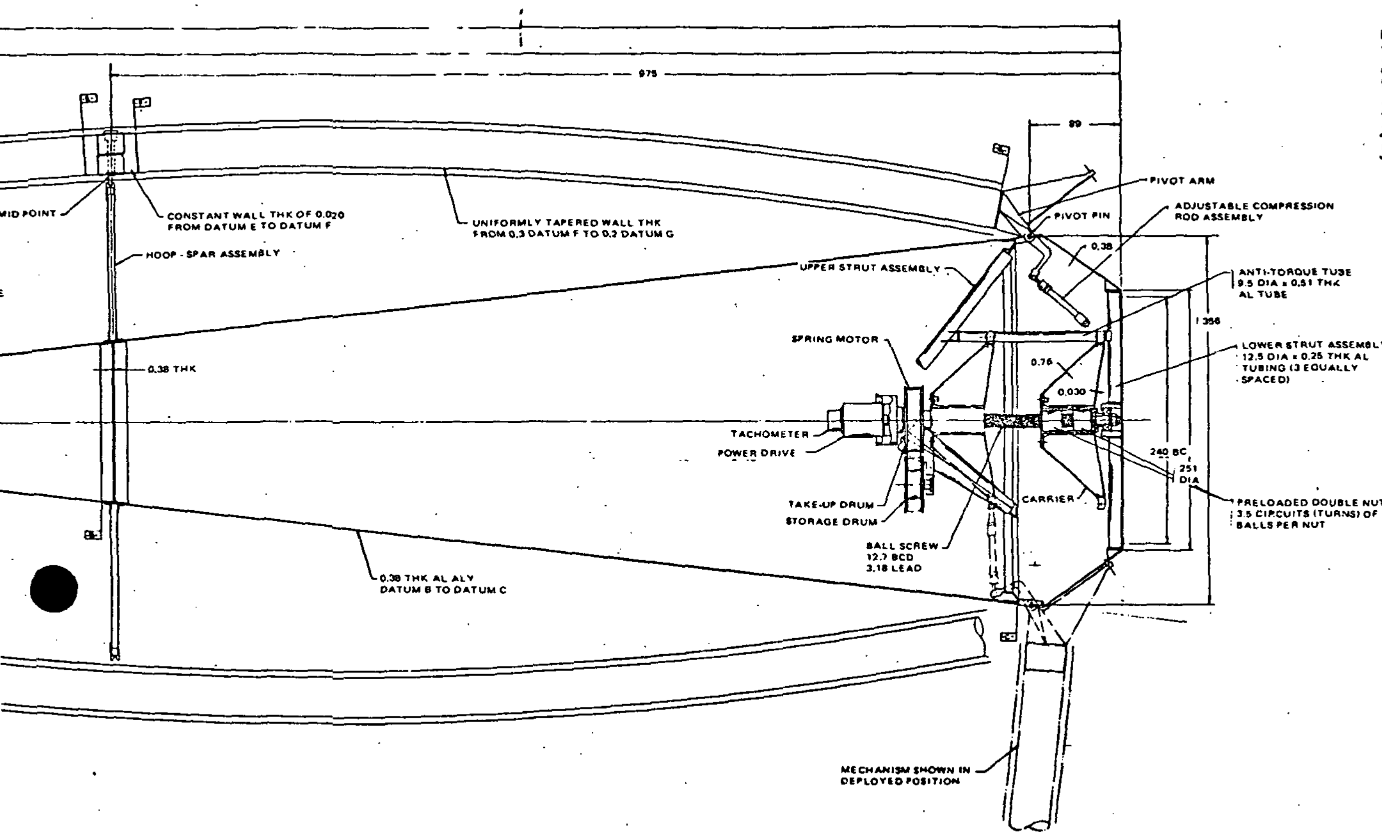


DIMENSIONS IN MILLIMETERS

Figure 4-12. S Band High Gain Antenna Layout


975
89
PIVOT ARM
ADJUSTABLE COMPRESSION ROD ASSEMBLY
PIVOT PIN
0.38
MID POINT
CONSTANT WALL THK OF 0.020 FROM DATUM E TO DATUM F
UNIFORMLY TAPERED WALL THK FROM 0.3 DATUM F TO 0.2 DATUM G
HOOP - SPAR ASSEMBLY
UPPER STRUT ASSEMBLY
ANTI-TORQUE TUBE 9.5 DIA x 0.51 THK AL TUBE
1 356
SPRING MOTOR
LOWER STRUT ASSEMBLY 12.5 DIA x 0.25 THK AL TUBING (3 EQUALLY SPACED)
0.38 THK
0.76
0.030
TACHOMETER
POWER DRIVE
240 BC
251 DIA
TAKE-UP DRUM
STORAGE DRUM
CARRIER
PRELOADED DOUBLE NUT 3.5 CIRCUITS (TURNS) OF BALLS PER NUT
BALL SCREW 12.7 BCD 3.18 LEAD
0.38 THK AL ALY DATUM B TO DATUM C
MECHANISM SHOWN IN DEPLOYED POSITION

20461-404(U)

spacecraft. The required surface precision of 0.150 cm rms at S band ...ency is accomplished by use of a reflective front mesh and a contour ...sting back mesh.

The reflective mesh is constructed from five-strand bundles of ... micron Chromel-R wire knitted into a wire screen. The mesh is knitted ... openings of 2 mm. The back mesh is knitted with 1.27 cm openings ... it is used as a secondary drawing surface for contouring the front mesh ...ile minimizing the antenna weight. The mesh is attached to the ribs in a ...sioned state.

Deployment of the reflector from the stowed to the fully open position ... precisely controlled to prevent impact loading of the rib structures and ...esh, thereby assuring that 1) the preset parabolic surface is not distorted ... the deployment action and 2) no mesh loading conditions result that exceed ...e mesh strength limits. The deployment mechanism shown in Figure 4-12 ...ilizes redundant energy drive systems to rotate a ball screw within a recirculating ball nut. The resultant linear motion of the ball nut serves to rotate each rib from the stowed to deployed position through the individual ...nkages to each rib. The primary drive of this system is a constant torque spring motor. This spring motor provides sufficient energy to deploy the antenna in any orientation under gravity conditions. In a zero gravity condition, the spring motor capability exceeds the deployment energy requirements. A backup drive system of two miniature torque motor functions then as dynamic brakes, controlling the deployment and requiring no electrical power. If required to deliver power, the motors can increase the torque to the ball-screw by as much as a factor of four. Latching in the deployed condition is accomplished by driving the ball nut carrier and linkages through an overcenter condition (relative to the pivot arms).

The mechanical design of the S band reflector has been generated by Radiation Incorporated and it is based on their AAFE 12.5 foot diameter Ku band antenna design. The antenna mass is projected to be 8.3 kg. Electrical performance projections are summarized in Table 4-20.

4.3.3.3 The S Band Order Wire Antenna

The S band order wire antenna is electrically identical to the UHF antenna except scaled to S band. The reflector is made from perforated sheet metal for low cost and light weight. Single sense circular polarization is generated by slot fed crossed dipoles. The antenna performance parameters are listed in Table 4-21.

4.3.3.4 The Ku Band High Gain Parabolic Reflector Antenna

The Ku band high gain parabolic reflector antenna (Figure 4-13) consists of a 1.42 meter diameter rigid rib and mesh lightweight reflector of 1.4 kg and a multimode-horn feed with a cassegrainian subreflector all

TABLE 4-20. S BAND HIGH GAIN ANTENNA PERFORMANCE

Frequency, MHz		2070	2250
Aperture area gain ($4\pi A/\lambda^2$)		38.45	39.06
Spillover and amplitude taper losses	1.35 dB		
Phase loss	0.09 dB		
Blockage loss	0.10 dB		
Reflector cross-polarization loss	0.10 dB		
Reflector surface loss (0.060 inches rms)	0.11 dB		
Reflector mesh I^2R loss	0.05 dB		
Hybrid losses	0.20 dB		
Coaxial cable loss (1.5 meters)	0.35 dB		
VSWR loss (1.4:1)	0.12 dB		
Total losses, dB		2.47	2.47
Antenna peak gain, dB		35.98	36.59
Polarization sense		Circular (Orthogonal)	Circular (Orthogonal)

mounted on a two-axis positioner for beam positioning. Amplitude taper across the reflector is significantly reduced by distorting the shape of the subreflector away from a hyperboloid. A corrugated horn gives rise to the two modes needed to make the feed pattern symmetrical with very low sidelobes. The polarizer that generates a single sense of circular polarization consists of a waveguide orthomode tee for good impedance match and a multiple iris phase shifter for good polarization ellipticity.

A set of 12 tubular aluminum ribs is used with the double mesh technique as described previously to form the reflective surface. The front mesh openings are 0.152 cm in size. The mesh surface tolerance is held to better than 0.0254 cm rms. The supporting ribs are 3.18 cm in diameter with a tapered wall of 0.0102 dm at the rib root to 0.0152 cm at the top. The ribs are made from 6061 T6 drawn aluminum tubing. Thermal control consists of multilayer blankets.

Receiver Ku Band Antennas

Two receiver Ku band antennas will each cover the northern hemisphere with circular polarized beams. The approximate beamwidth requirements

are 0.157 by 0.314 radians. An array of two fin-loaded pyramidal horn antennas satisfies the CP beam coverage requirements over the 13.4 to 14.2 GHz transmit frequency. A four-iris square guide polarizer and an orthomode tee are used. For simplicity, the unused orthogonal arm of the orthomode tee has been shorted out.

The RF performance characteristics for the Ku band receive horns and transmit antenna reflector are summarized in Table 4-22 and 4-23.

TABLE 4-21. S BAND ORDER WIRE ANTENNA PERFORMANCE

Frequency band		2200 to 2290 MHz
Aperture diameter		26.7 cm
Aperture gain*		15.0 dB
Reflector surface loss	0.01 dB	
Reflector I^2R loss	0.01 dB	
Hybrid loss	0.16 dB	
Coaxial cable loss	0.01 dB	
VSWR loss (2.0:1)	0.50 dB	
Total losses		0.69 dB
Antenna peak gain		14.3 dB
Antenna FOV gain (±15 deg)		11.4 dB
Polarization sense		Circular

*L. R. Dod, "Backfire Yagi Antenna Measurements."

TABLE 4-22. Ku BAND HORN ANTENNA PERFORMANCE

Frequency		13.7 GHz
Aperture area gain ($4\pi A/\lambda^2$)		25.1 dB
Amplitude taper and phase losses	1.93 dB	
Horn I^2R loss	0.03 dB	
Polarizer and transition I^2R loss	0.30 dB	
Waveguide loss (30.4 cm)	0.25 dB	
VSWR loss (1.3:1)	0.08 dB	
Total losses		2.59 dB
Antenna peak gain	22.5 dB	
Antenna earth-edge gain (±9.1°)		18.5 dB
Polarization sense		Circular

4.3.3.5 Telemetry Tracking and Command VHF Antenna

The telemetry, tracking, and command antenna consists of eight whip antennas fed by a hybrid balun. The eight whips are attached to the edge of the solar panel and are equally spaced. Each whip is tilted away from the spin axis at an angle of 1.05 radians and is driven 0.786 electrical radians out of phase with adjacent whips for best radiation coverage. The phase sequence is in opposite directions for the two terminals of the hybrid balun that attach to the diplexers. The radiation pattern of the antenna [illegible] is elliptically polarized. Table 4-24 summarizes the antenna performance data.

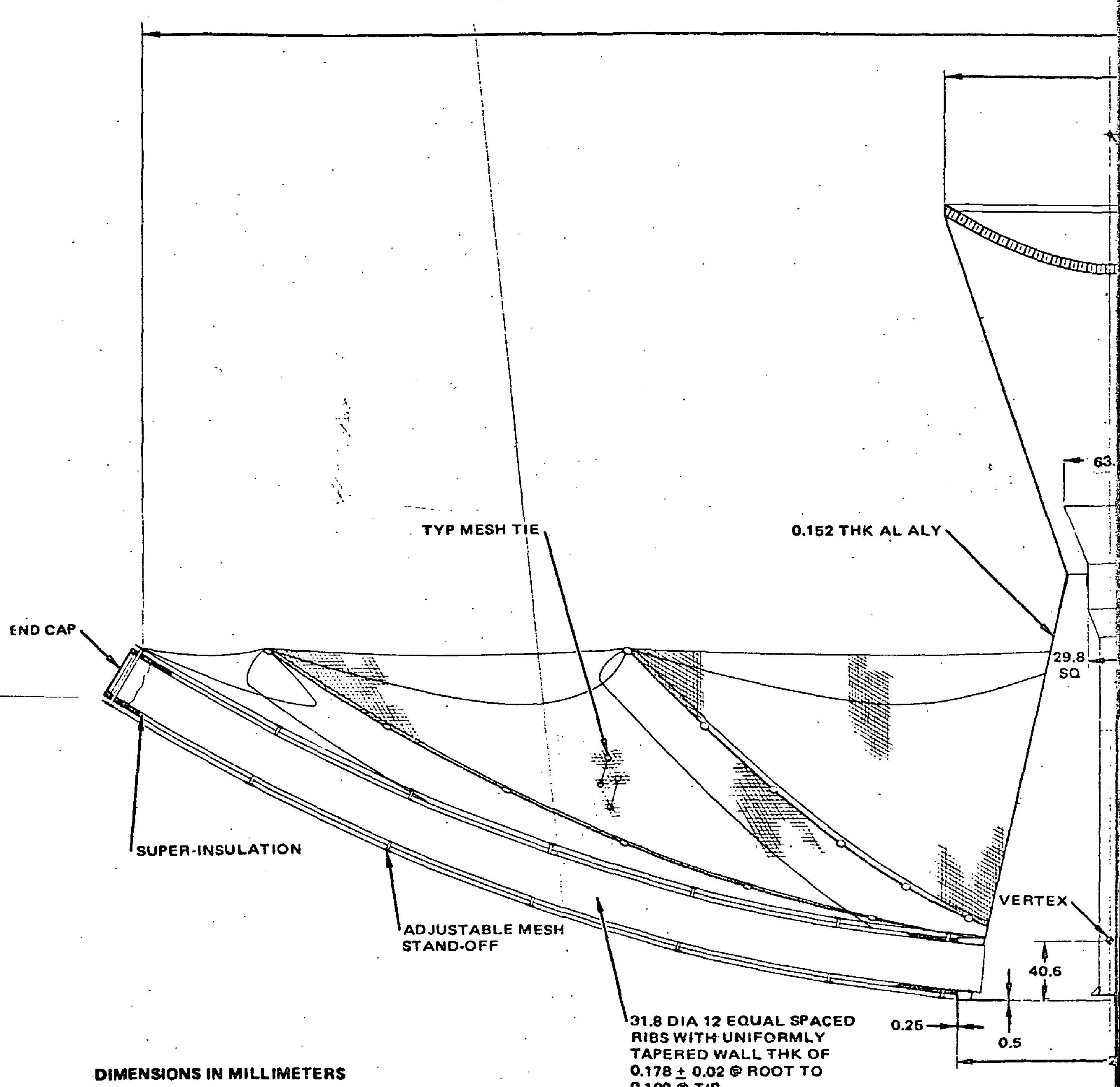


Figure 4-13. Ku Band Antenna Layout

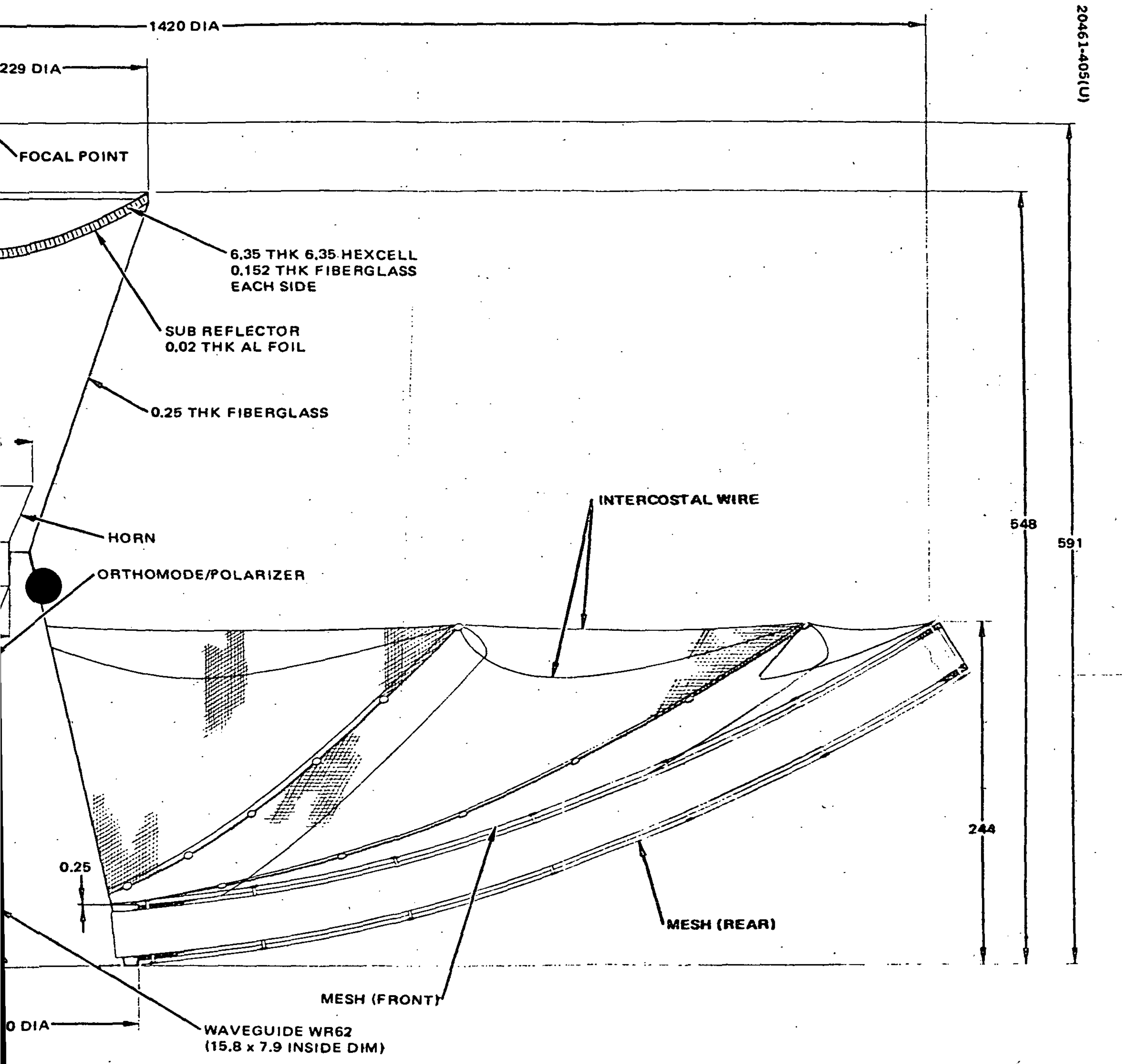

1420 DIA
229 DIA
FOCAL POINT
6.35 THK 6.35 HEXCELL
0.152 THK FIBERGLASS
EACH SIDE
SUB REFLECTOR
0.02 THK AL FOIL
0.25 THK FIBERGLASS
HORN
ORTHOMODE/POLARIZER
INTERCOSTAL WIRE
548
591
244
0.25
MESH (REAR)
MESH (FRONT)
WAVEGUIDE WR62
(15.8 x 7.9 INSIDE DIM)
0 DIA
20461-405(U)

TABLE 4-23. Ku BAND REFLECTOR ANTENNA PERFORMANCE

Frequency		14.9 GHz
Aperture area gain ($4\pi A/\lambda^2$)		46.94 dB
Spillover and amplitude taper losses	0.86 dB	
Phase loss	0.05 dB	
Blockage loss	0.30 dB	
Reflector cross-polarization loss	0.02 dB	
Reflector surface loss (0.010 inches rms)	0.10 dB	
Reflector mesh I^2R loss	0.15 dB	
Horn I^2R loss	0.02 dB	
Polarizer and transition I^2R loss	0.30 dB	
Waveguide loss (9.5 inches)	0.04 dB	
VSWR loss (1.3:1)	0.08 dB	
Total losses		1.92 dB
Antenna peak gain		45.02 dB
Polarization sense		Circular

TABLE 4-24. TELEMETRY, TRACKING AND COMMAND ANTENNA PERFORMANCE

Telemetry frequency band	136 to 138 MHz
Array gain over 95 percent of sphere (for matched polarization)*	- 4.0 dB
Hybrid balun I^2R loss	2.0 dB
Antenna gain over 95 percent of sphere (for matched polarization)	- 6.0 dB
Command frequency band	148 to 154 MHz
Array gain over 97 percent of sphere (for circular polarization)	-11.0 dB
Hybrid balun I^2R loss	2.0 dB
Antenna gain over 97 percent of sphere (for circular polarization)	-13.0 dB

*Polarization combining at the ground station constitutes matched polarization.

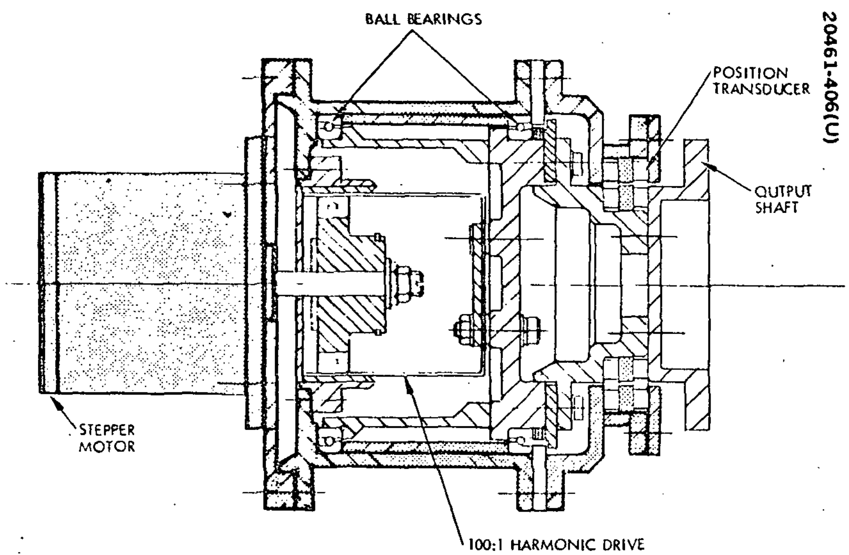


Figure 4-14. Antenna Positioner Drive Unit

4.3.3.6 Two-Axis (Elevation and Azimuth) Tracking Mechanisms

Two-axis (elevation and azimuth) tracking mechanisms are employed for S band and Ku band antenna reflector pointing over a range of ±16 degrees. Identical motor drive assemblies are jointed by a gimbal structure resulting in an elevation over azimuth configuration. The gimbal assembly is supported in each axis by the preloaded angular contact ball bearings of the motor drive assembly and by an outboard radial deep groove bearing. Dry film lubrication is used throughout the mechanisms for temperature range compatibility and to avoid the need for sealing the moving elements. The S band antenna positioner employs coaxial rotary joints for low RF loss (total of 0.2 dB). The Ku band drive mechanism has rotary waveguide RF power transmission across its axes.

The drive mechanism is powered by a permanent magnet, bifilar-wound, phase switched stepper motor producing 200 steps per revolution (1.8 degrees per step). The motor provides ample torque at stepping rates beyond the maximum required for this application and provides positive magnetic holding torque when power is removed. The transmission selected is a high ratio harmonic drive with a reduction of 144:1 resulting in a nominal gimbal movement of 0.0125 degrees for each pulse to the stepper motor. The antenna positioner drive unit is shown in Figure 4-14.

4.3.4 Attitude Control

The attitude control system controls the spacecraft stability, provides a stable platform for antenna positioning, and monitors the orientation of the vehicle spin vector and despun platform azimuth for precision antenna pointing. The TDR Gyrostat spacecraft configuration develops gyroscopic rigidity by its spinning rotor, and attitude stability is achieved by passive energy dissipation from the despin nutation damper and by active nutation damping through the despin control system.

The functional criteria and design requirements for the spin axis attitude control are:

1) Attitude control subsystem must provide vehicle asymptotic nutational stability, with residual nutation consistent with antenna pointing accuracy requirements.

2) Nutation transients that occur in normal operation must be rapidly damped.

3) Vehicle must be autonomously stable in failure modes involving large nutation angles.

4) Spin axis control requirements are north-south error allocation ≤ 0.10 degrees, orientation determination ≤ 0.20 degrees, and system nutation damping time constant ≤ 300 seconds.

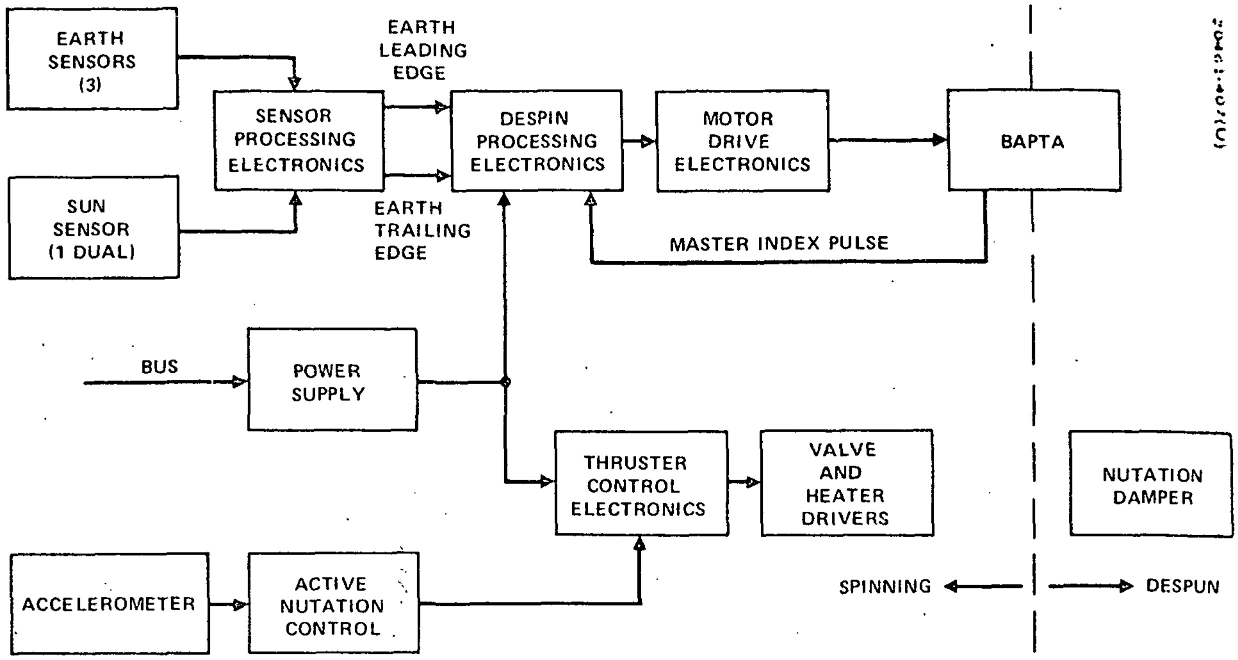


Figure 4-15. Attitude Control Subsystem Block Diagram

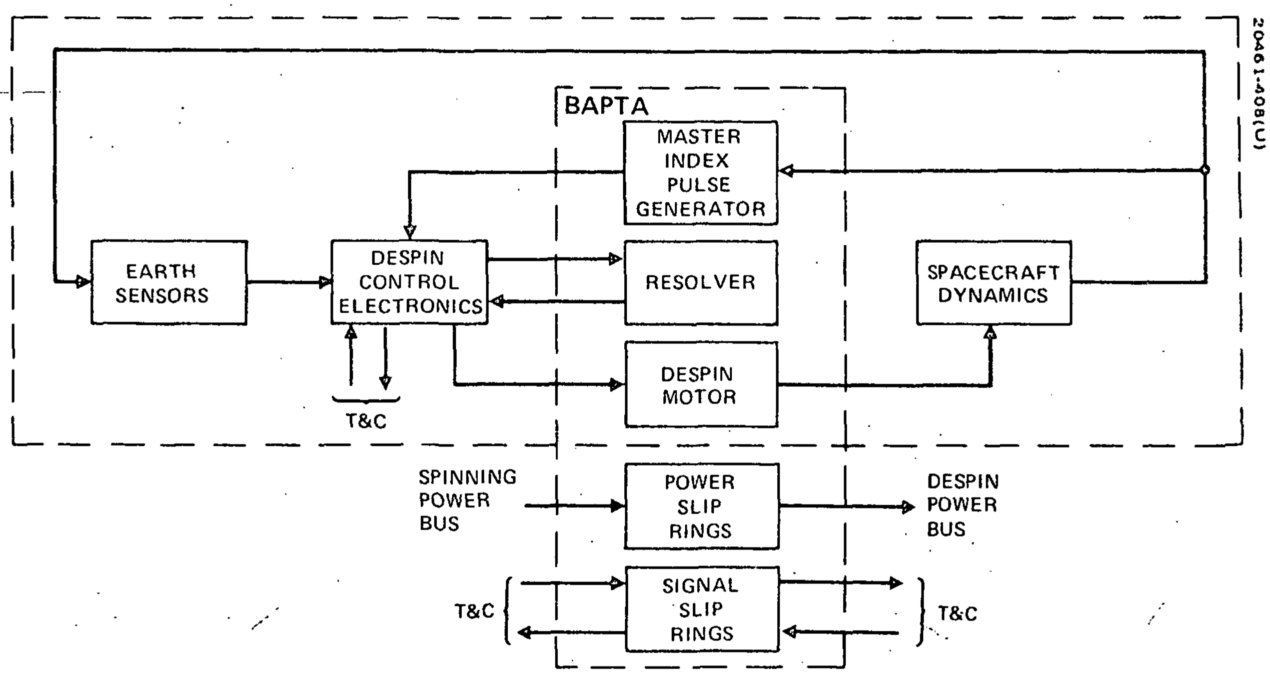


Figure 4-16. Despin Control Subsystem Block Diagram

A functional block diagram of the attitude control subsystem is given in Figure 4-15. Determination and control of the spin axis attitude is accomplished by using rotor mounted sun and earth sensors. The sun sensor provides pulse pairs for measurement of the angle between the sun line of sight and the spacecraft spin axis, while the earth sensors provide earth chord-width information for attitude measurements. Corrections to the attitude are made using ground commanded pulsing of the jets.

Sensor information for attitude determination is processed by the Hughes ATDET computer program. This program models disturbance torques, sensor biases, and attitude commands and produces a least squares fit of attitude to the data. The processing algorithm used permits on-orbit calibration of the sensors and updating of solar torque estimates. During transfer orbit, attitude may be determined to 0.2 degree (3 sigma) accuracy, on-orbit accuracy of 0.03 degree (3 sigma) after calibration of sensor biases is achieved.

The TDRS attitude stabilization design incorporates despin central damping of nutation along with using the passive, platform mounted, eddy current nutation damper.

In addition to the techniques for stabilizing the nutation by action of internal elements, an active backup nutation control (ANC) loop using reaction jets has been incorporated to stabilize nutation in a failure mode or to reduce transient nutation during the apogee motor firing and antenna deployment phases of the mission. The methodology of actively controlling nutation is the following:

1) An accelerometer detects the presence of nutation and establishes the phase and amplitude of the motion with respect to a rotor-fixed coordinate system.

2) The accelerometer output signal is threshold detected, amplified, and converted to a jet command.

3) The axial jet fires once per nutation cycle for a portion of the cycle which results in the application of a transverse torque in opposition to the nutation motion.

A simplified block diagram of the despin control subsystem (DCS) is given in Figure 4-16. Three independent earth sensors are mounted on the spinning rotor and are used to supply rotor phase information relative to the earth center to the despin control subsystem. For on-station operation only a single earth sensor is required for despin control. Use of three elevation orientations allows selection of the sensor to be used by ground command well in advance of sun or moon interference and provides adequate redundancy.

The bearing and power transfer assembly (BAPTA) provides electrical and mechanical interconnection between the spinning and despun sections

of the satellite. The BAPTA consists of a bearing assembly, a motor drive assembly, and a slip ring assembly for signal and power transfer between the spun and despun sections of the spacecraft.

The despin control electronics (DCE) processes the inertial rotor phase information from an earth sensor and the relative platform phase information from the MIP (sampled once every rotor spin revolution) and generates continuous control torque commands to the BAPTA torque motor. It contains both rate and tracking loop control logic to ensure automatic despin of the platform and acquisition of the earth. The DCE contains the loss of sensor detection logic to provide platform rate stability in the event of loss of an earth sensor and accepts ground commands for platform rate control and failure mode ground despin control.

There are four basic operating modes for the despin control subsystem:

1) In the normal tracking mode, the despin system aligns the despin antenna boresight to the center of the earth as sensed by the spinning earth sensors. Because of the wide variation in platform inertia due to antenna deployment, a low gain tracking mode has been implemented for initial orbital operation of the despin subsystem. When the DCE is turned on, a control loop gain lower by a factor of 2.5 below normal gain is activated. Once initial orbit is achieved and the antennas are deployed, the higher gain mode is selected by ground command.

2) The rate control mode uses an inner rate loop to ensure automatic despin and acquisition during initial rotor spinup and following apogee boost. A three level ground commandable ±2.1 or -0.42 rad/sec rate bias is included in the DCE for controlling the platform cg offsets. The magnitude of the maximum commandable rate torque is scaled so as to override the tracking loop and generate the desired platform rate.

3) In pseudo earth mode, the tracking and rate loops operate using ground transmitted leading and trailing edge pulses, which are locked in frequency to the rotor spin rate. The required spin synchronous pulse train is obtained by use of the sun sensor pulses which are available on real time FM telemetry. An additional sun pulse delayed by 0.244 radian of spin phase from the telemetry sun pulse is created. This pulse train is then sent through the normal command channel to the despin control electronics. By controlling the phase of the retransmitted pulses with respect to the original sun pulse, the azimuth orientation of the payload antenna can be controlled.

4) In the event of loss of earth sensor pulses, automatic onboard logic will supply a once per revolution pulse to the rate control logic. The pulse frequency is based on a fixed clock rate (internal to the DCE) set to the nominal spin speed. Therefore, in event of a sensor loss, a slight platform rate will develop due to deviations in actual spin speed from the nominal. By ground commanding an alternate sensor, automatic despin and reacquisition will occur.

Signal Processing

Determination of the platform orientation is accomplished by means of an earth center-finding technique. The linear range of the error detection is 0.122 radian for north earth and south earth oriented sensors and ±0.140 radian for the center earth sensor. For errors beyond the linear range (as in the case when the platform is rotating), the sensed error is held at plus or minus the saturation value by the DCE. By use of an electronically generated delayed MIP, which is π radians away from the actual MIP, the pointing error characteristic can be achieved. This ensures the correct platform direction of rotation during acquisition for shortest acquisition time.

Determination of inertial platform rate is accomplished by measuring the change in platform position over one rotor spin revolution. The rate logic utilizes the earth leading edge and MIP pulses along with a fixed frequency clock, to form, digitally, this first-back-difference of position. At the occurrence of the earth leading edge pulse an upcounter is set to zero and proceeds to then count from the leading edge pulse to the MIP, using a crystal controlled oscillator as the basic count clock. At the occurrence of the MIP the number occurring in the upcounter is transferred to a downcounter and the downcounter is allowed to count from the next leading edge to MIP. At the occurrence of each MIP, the number contained in the downcounter represents the change in platform position over one sample.

The operation of the tracking loop is illustrated in the block diagram Figure 4-17. The sample and hold output of the position error detector is used to drive an analog shaping network whose dynamics have been selected to provide stable closed loop pointing control and meet the despin system requirements. The resulting output of the shaping network is a torque command to the BAPTA.

The motor used in the despin control subsystem is a two-phase, 16 pole, ac motor which requires in-phase sine and cosine driving voltages to generate the required rotating magnetic field. To operate as a dc motor, these sine and cosine voltages must be artificially generated. This is accomplished using a resolver in the BAPTA. A precise phase relation is maintained between the motor rotor and resolver by keying them to a common shaft. The resolver is excited by a 4 KHz carrier from the DCE. The sine and cosine resolver outputs are then synchronously demodulated to remove

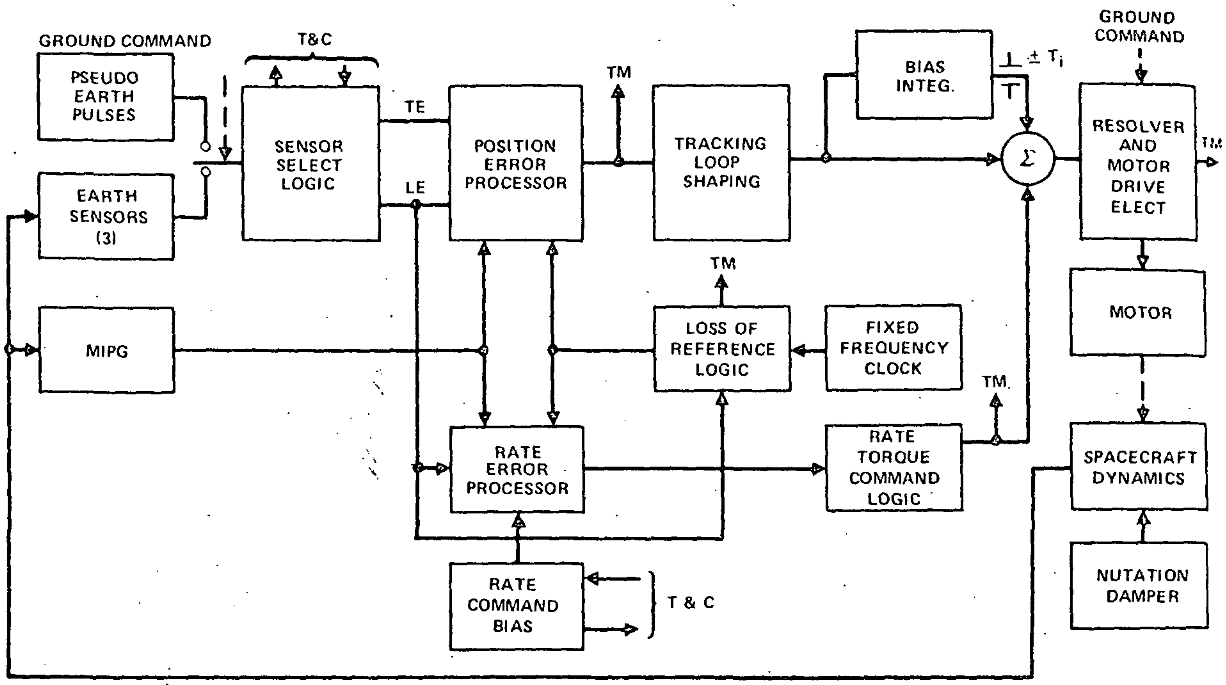


Figure 4-17. Despin Control Electronics Functional Block Diagram

the carrier and amplified to drive the redundant BAPTA motor sine and cosine windings. One sine/cosine pair are driven by the motor driver circuits in a single despin control electronics unit. However, the DCE motor driver inputs are cross-strapped so that each DCE can drive either or both of the motor driver/motor pairs.

Under stall conditions, the maximum motor torque with a single motor driver active torque is 2.98 Newton meters. As the relative rate increases, a back electromagnetic force (EMF) is developed in the motor stator windings; therefore, the torque is limited by the maximum available driving voltage which is 19 volts at the motor winding under worst case end of life conditions (24 volt bus). At 10.4 rad/sec and at the expected BAPTA temperature of 294K, the nominal friction level is 0.20 Newton meter. This implies a torque margin ratio of 7-1/2:1 for the low bus voltages for each motor.

When the DCE receives power, it turns on with several of the internal stages in preferred states. The DCE last utilized (ground command selected) is activated in the low gain mode. Both motor drivers are active and the ground mode logic is off. The rate bias is zero and center earth sensor is selected as the despin reference. This initialization logic is in part determined by the system requirement to recover automatically from a flatspin condition due to battery failure upon exit from eclipse.

The DCS performance characteristics were analyzed, and, based on frequency-domain analyses, a lead/quadratic lag followed by lead/integral shaping network was selected. The dc gain and integrator gain were chosen as high as possible to minimize sensitivity to friction torque, while avoiding excessive gain to sensor noise. The system gain margin is 12 dB, while the phase margin is 0.77 radian. These stability margins are sufficient to accommodate all modes of operation and parameter variations over the mission.

4.3.5 Reaction Control Subsystem

The reaction control subsystem achieves attitude control of the spacecraft during its life span in orbit and it provides for spacecraft station changes. Its elements are four redundant thrusters, four propulsion tanks, with a propellant isolation valve (latching valve) in between sets of two tanks, fill and drain valves, and pressure transducers.

The propellant is hydrazine with a specific impulse of 227 seconds. A propellant loading of 55 percent of the tank capability is used which provides for the following spacecraft maneuvers and attitude corrections:

- 130 degree precession for alignment of the apogee motor prior to firing
- 120 degree precession for spacecraft operational positioning after firing

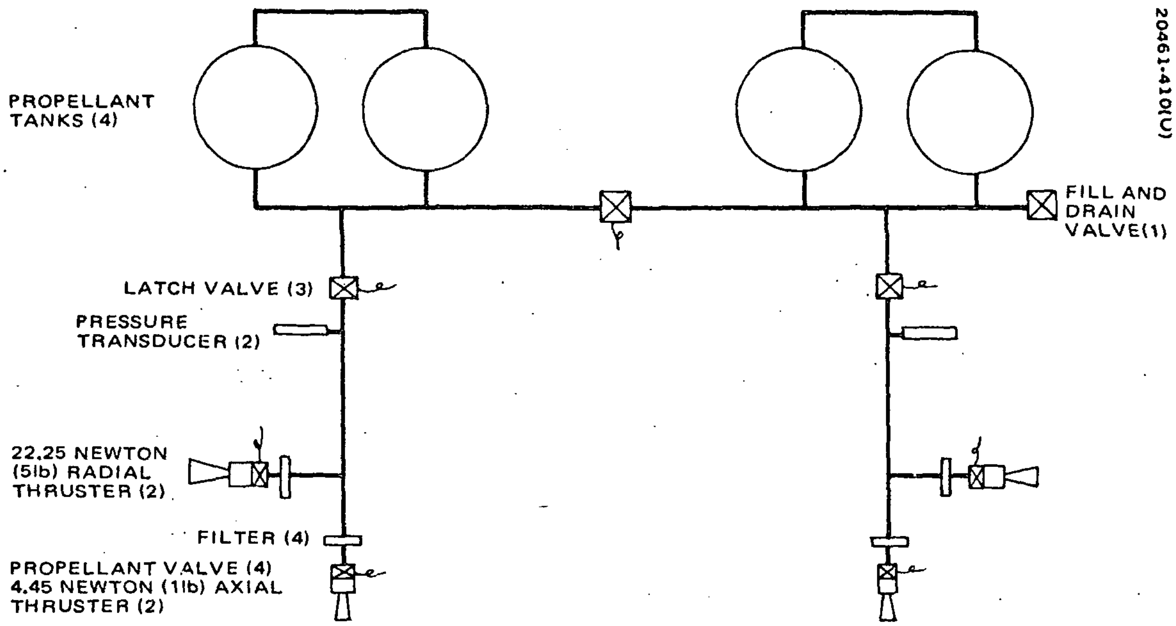


Figure 4-18. RCS Design Schematic

- 7 years of solar torque correction assuming 8.3 cm cp-cg separation and 80 percent antenna porosity
- 2 percent margin for jet misalignment compensation
- Injection trim for booster and apogee motor errors
- Two 0.0775 radian (4.5 degree) station changes per day
- 7 years of east-west stationkeeping

The RCS performance requirements for the TDRS are summarized in Table 4-25 and its functional design is illustrated in Figure 4-18.

There are two 4.45 Newton axial thrusters and two 22.25 Newton radial thrusters for complete system redundancy. Each thruster has its own etched disc type filter and each half system has its own pressure transducer. The thrust chamber of these thrusters is a Hughes qualified design and their integral dual seat propellant valves are of Hydraulic Research design.

A flight qualified liquid filter, developed by Vacco Corporation, is used. This filter consists of multiple chem milled discs stacked to form the filter element. The Vacco filter is verified free of particulates to the degree specified by CS 31023-400.

The propellant isolation valve for the TDRS application is a latching solenoid valve developed and qualified by Carleton Controls Corporation. This valve (Figure 4-19), employs a soft teflon seat and it contains an opening and closing coil. The valve poppet is held either in the open or closed

TABLE 4-25. RCS REQUIREMENTS

Performance			
ΔV			168.25 m/sec (552 fps)
Cumulative impulse predictability for			
		<10 pulses	20 percent
		>10 pulses	10 percent
Burn time:	Steady state		None
	Pulse	Axial	70,000
		Radial	30,000
Cold starts:	Axial		1250
	Radial		30
Physical			
Mass:	Subsystem dry		10.43 kg (23.0 lb)
	Propellant and gas		37.20 kg (82.0 lb)
Environmental			
Temperature range			278 to 333 K (40 to 140°F)

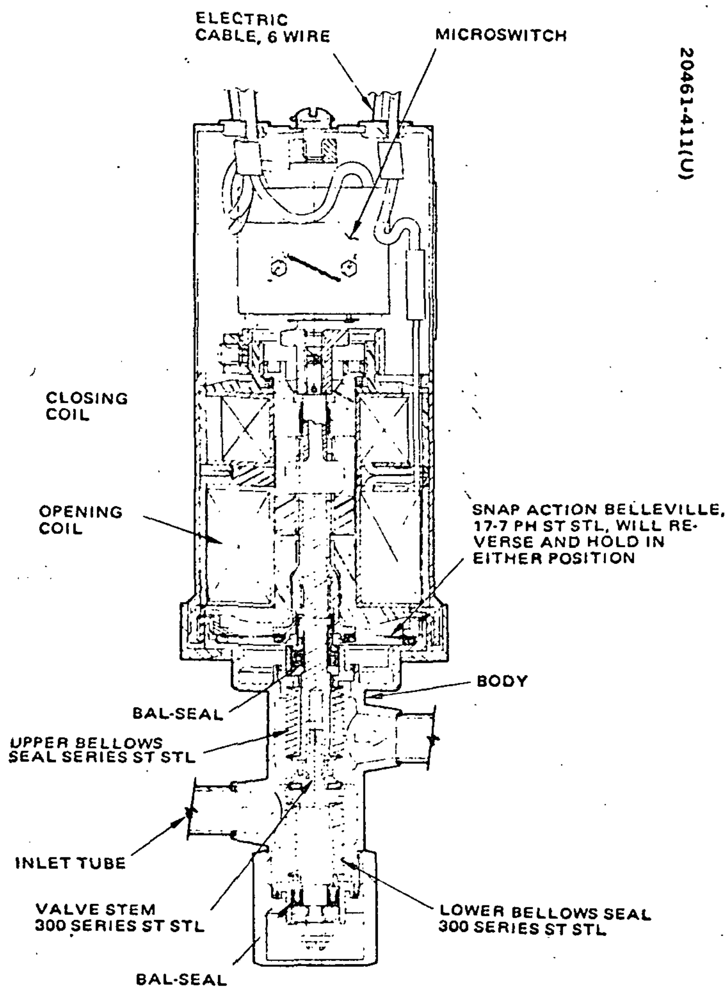


Figure 4-19. Propellant Latching Valve

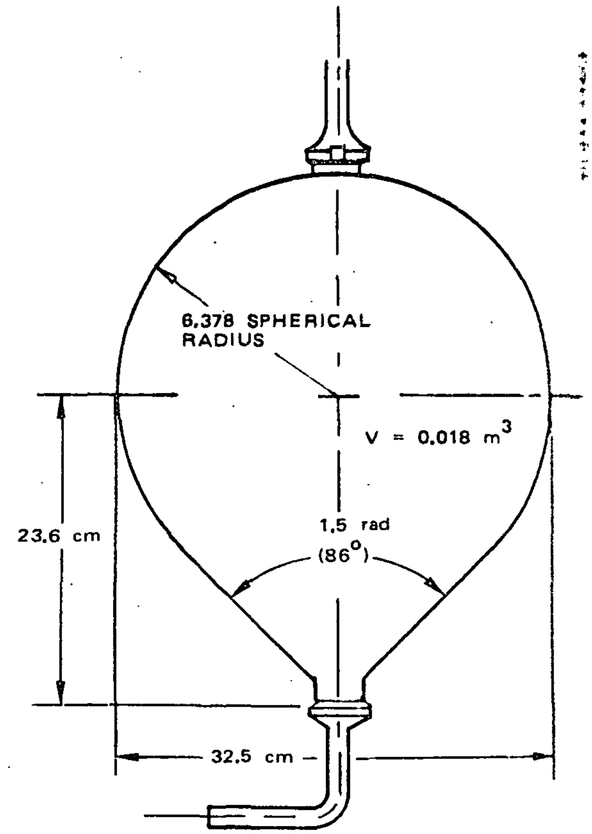


Figure 4-20. Propellant Tank

position without electrical power by a Belleville spring washer. Pulsing the closing coil pulls the armature, fastened to the poppet, to the closed position. After removal of the power, the valve remains held in the closed position by the Belleville spring. 20 ms pulses are required to actuate the valve, although it has been designed and qualified to withstand continuous power for 120 seconds over the temperature range of 278 to 333K. The valve is equipped with a single pole, double throw microswitch actuated by the armature so that valve position can be determined by either ground support equipment or by telemetry if desired. A small 25 micron absolute wire screen filter is added to the inlet port of the valve to improve valve reliability. External leakage is kept to a minimum by use of an all welded valve assembly using metal bellows as seals. All components exposed to propellant are made from stainless steel or teflon.

The propellant tank consists of a 32.5 cm sphere integrated with an 86 degree cone as shown in Figure 4-20. It is fabricated from 6Al-4V titanium by Sargent Industries. Design operating pressure is 400 psig and burst pressure is 1600 psig. Total volume is 0.018 m^3 (1100 in^3) minimum per tank. The cone is located down and away from the satellite spin axis. Thus, 100 percent expulsion efficiency is possible with only two ports, since the fluid port is at the low point in the tank during both static ground servicing and in the in-flight spinning mode.

The pressure transducer is a potentiometer of a flight qualified design. The potentiometer slide wire is actuated by pressure displacement of a welded pressure capsule referenced against vacuum.

The fill and drain valve (Figure 4-21) is used in both the gas supply and propellant supply systems. The gas valve uses an inlet fitting per MS 24385-2, and the propellant valve uses a MS 24385-4 inlet fitting to prevent gas/liquid connection errors. The valve is a manually operated shutoff valve using a tungsten carbide ball forced into the valve body seat to seal the flow passage. The ball is retained in a stem assembly and is moved axially on and off the seat when the retainer nut is rotated on the valve body. A cap is provided to cover the MS 24385 inlet port when the valve is in the closed position. After system loading and before flight, an aluminum closure cap is added using K-seal at its base as an added redundant seal over the complete valve.

4.3.6 Electrical Power Subsystem

The electrical power subsystem supports operation of all payload and spacecraft subsystems. It is required to provide payload power continuously for a minimum of 5 years. The power requirement for the different operating modes for both the sunlit and eclipse portion of the orbit were shown in subsection 4.1.

The basic configuration of the power subsystem is shown in Figure 4-22. The power subsystem has two batteries with 18 cells each. Each

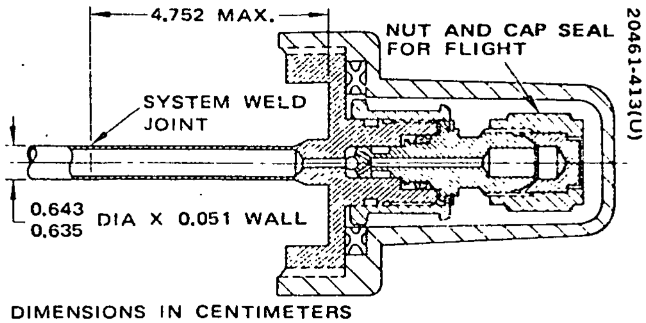


Figure 4-21. Fill/Drain Valve

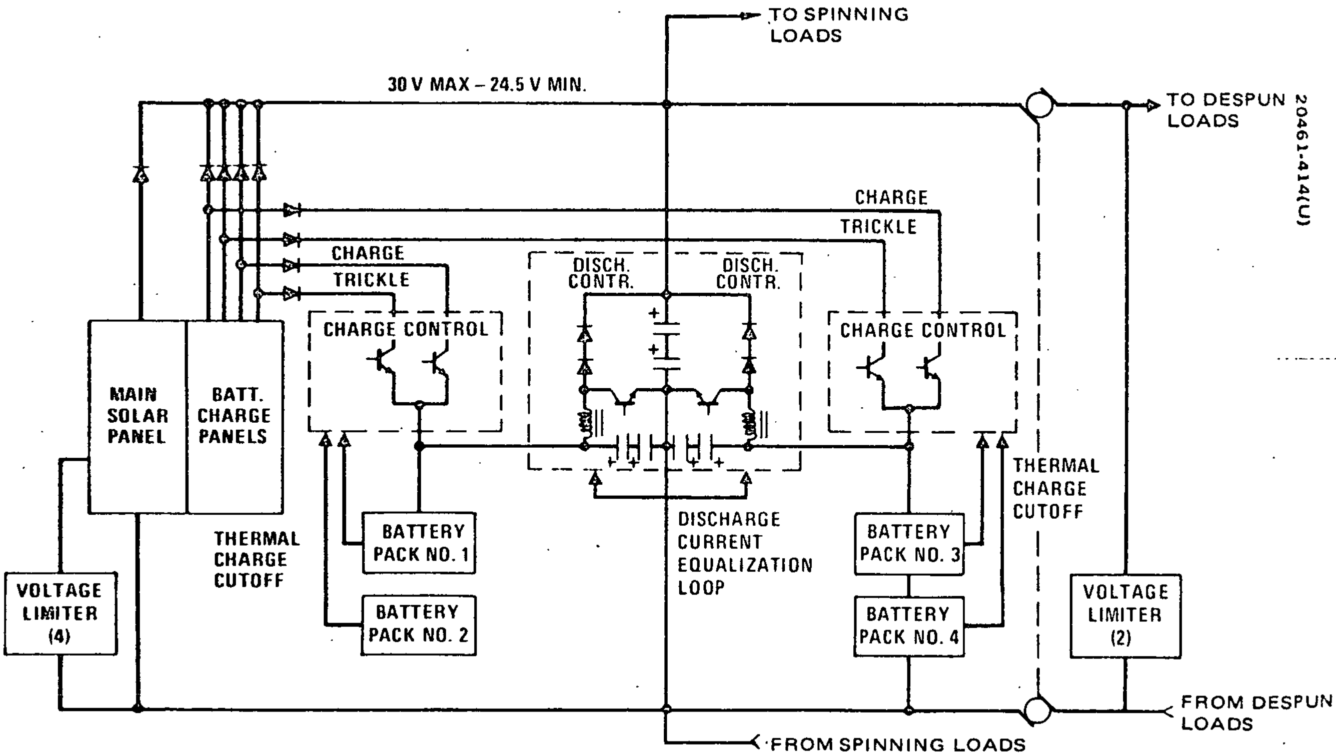


Figure 4-22. TDRSS Baseline Power Subsystem Block Diagram

battery is composed of two battery packs. The cells are 16 amp-hr in size. The battery output is boosted by a boost discharge regulator to 25.5 volt nominal regulated voltage. Power system operation with battery power augmentation during UHF voice communication will result in very shallow battery discharges. The battery control electronics incorporates capability for battery reconditioning. During battery charging, the solar array voltage will be 27.5 volts or higher. The batteries are charged at C/15 rate. Between eclipse periods, the batteries are trickle-charged. The trickle charge rate is C/60. The battery charge power provided by the solar array to the two batteries is 60 watts. The solar panel output is 364.0 watts at summer solstice and 399 watts 23 days before equinox.

Bus voltage limiters maintain solar panel output voltage below 30 volts independently of load after emerging from eclipse and provide a minimum heat dissipation on the despun platform during launch and orbit acquisition and also during powered down operation.

The power subsystem weight was listed in subsection 4.1, and design characteristics are listed in Table 4-26.

TABLE 4-26. POWER SUBSYSTEM DESIGN CHARACTERISTICS

Solar Cell Array	
Length:	2.21 meters
Diameter:	2.16 meters
Cells:	2 x 2 cm x 0.18 mm (7.2 mil) 10 ohm-cm
Covers:	2 x 2 cm x 0.15 mm (6.0 mil)
Batteries	
Number	2 with 18 cells each
Capacity	57,600 amp-sec (16 amp-hr)
Discharge cycles	
Eclipse	450 (<60 percent D.O.D.)
Augmentation	7000 maximum (<4.5 percent D.O.D.)
Battery Controller	
Current sharing tolerance	5 percent
Rated output current	10 amperes
Battery input potential	18 to 24 volts
Voltage Limiter, Maximum bus potential	30 volts

The solar cells arrays are mounted to the rotating spacecraft cylinder of 2.16 meters in diameter and 2.21 meter length. The solar cells are 2 by 2 cm, 10 ohm-cm resistivity, n/p type and are 0.18 mm (7.2 mil) thick cell with 0.15 mm (6 mil) coverglass. A total of 486 cell strings are in parallel and each string is 68 cells long. The solar array design factors are shown in Table 4-27. Battery charge termination is controlled by over-tempe ature sensing. The batteries begin charging after emergence from an eclipse and continue charging until all batteries are fully charged. A charge control electronic system as shown in Figure 4-23 is employed to provide for the following alternate controls: 1) automatic recharging of the batteries on exit from eclipse, 2) automatic charge termination, 3) ground control override for functions 1 and 2 on each battery separately, and 4) ground control of reconditioning discharge.

The battery discharge controllers are illustrated in Figure 4-24. These controllers maintain a regulated output voltage of 25.5 volt ±0.5 volt. The battery voltage can vary from 24.3 to 17.5 volts during discharge.

The discharge current of each battery is sensed with a magnetic current sensor, and an analog output from the sensor is provided to a current comparator circuit in each battery discharge control. This circuit acts to modify voltage control in each boost-choke stage to provide current sharing between batteries to within an allowable rating and battery depth of discharge. Shunt tap limiters and dissipative shunt bus limiters are used in the TDRS design.

Tap limiters are used to hold the bus voltage below 29.5 volts with full load applied, dumping surplus solar panel power at beginning of life by shunting or eliminating the current supplied by the tapped strings to the main bus. Tap limiters also clamp the bus at 30 volts after exiting eclipse. Four tap limiters, each shunting a separate section of the array (1/8 of total array in each section), are provided. The limiters have set points separated by 0.1 volt, so that operation is incremental.

Bus limiters place resistive loads across the bus when the bus voltage exceeds 29.5 volts. They replace some of the heat removed from the despun section during the transfer orbit, or any other time that spacecraft loads are low. Each bus limiter and its associated external load resistors dissipate a minimum of 110 watts at a bus voltage of 30.0 volts. Total dissipation for both bus limiters is 220 watts minimum at a primary bus voltage of 30.0 volts. With a primary bus voltage below 29.5 volts, the limiters are in a standby condition and dissipate a maximum of 0.58 watt. A performance summary of the TDRS power system design is provided in Table 4-28.

4.3.7 Apogee Motor

A solid propellant motor is used to inject the TDR satellite into a 7 degree inclined geosynchronous orbit. The apogee motor must be of

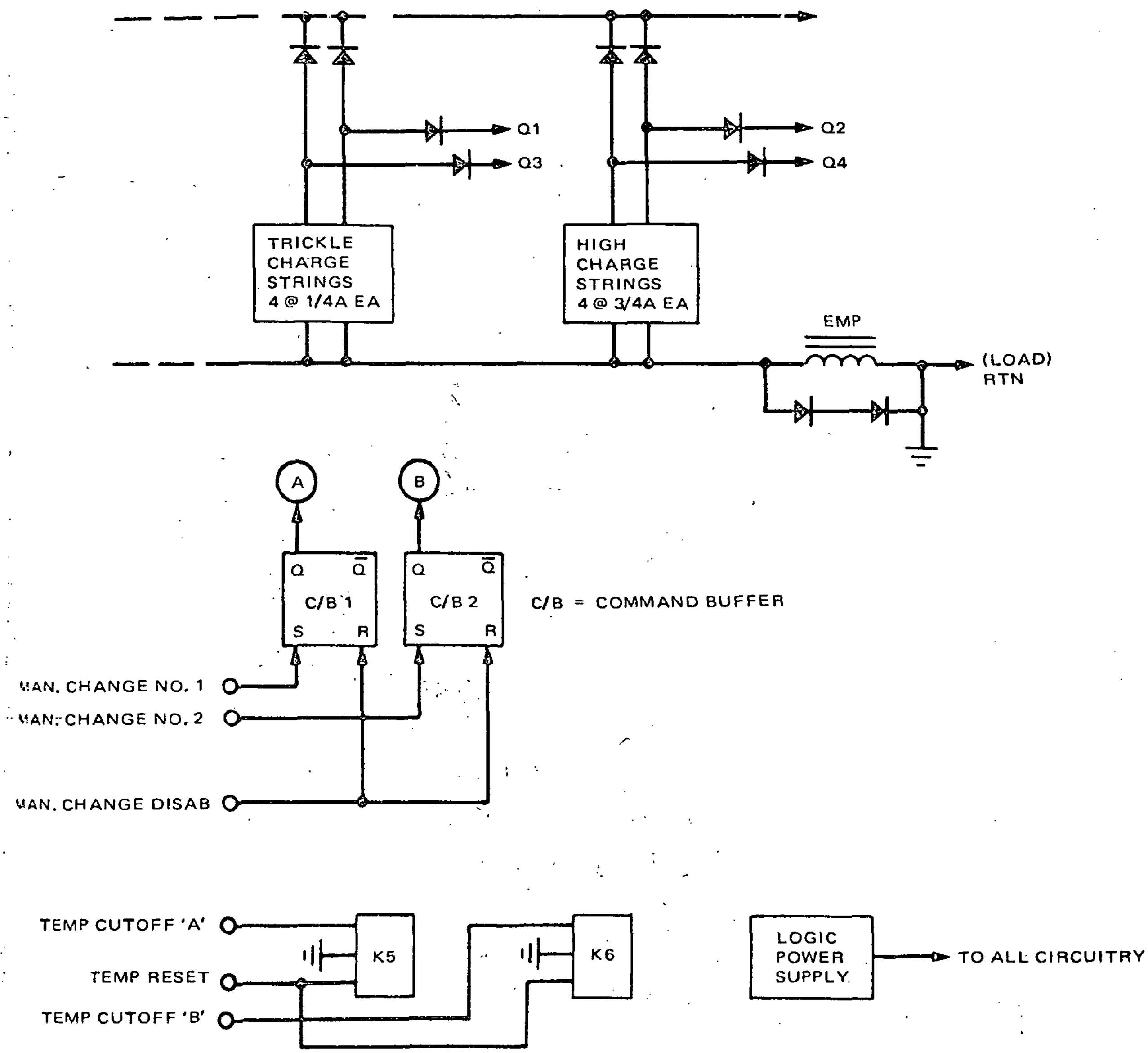
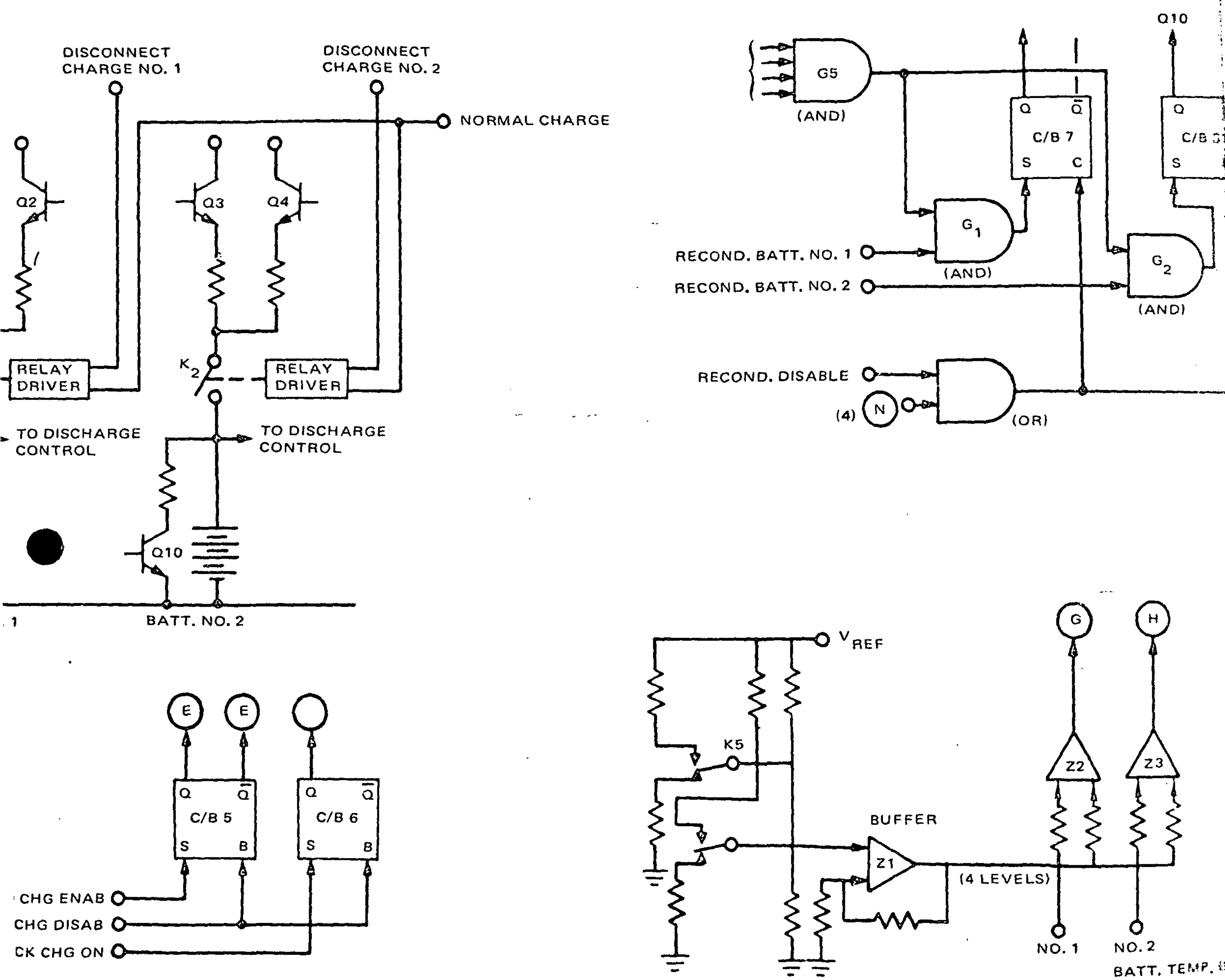
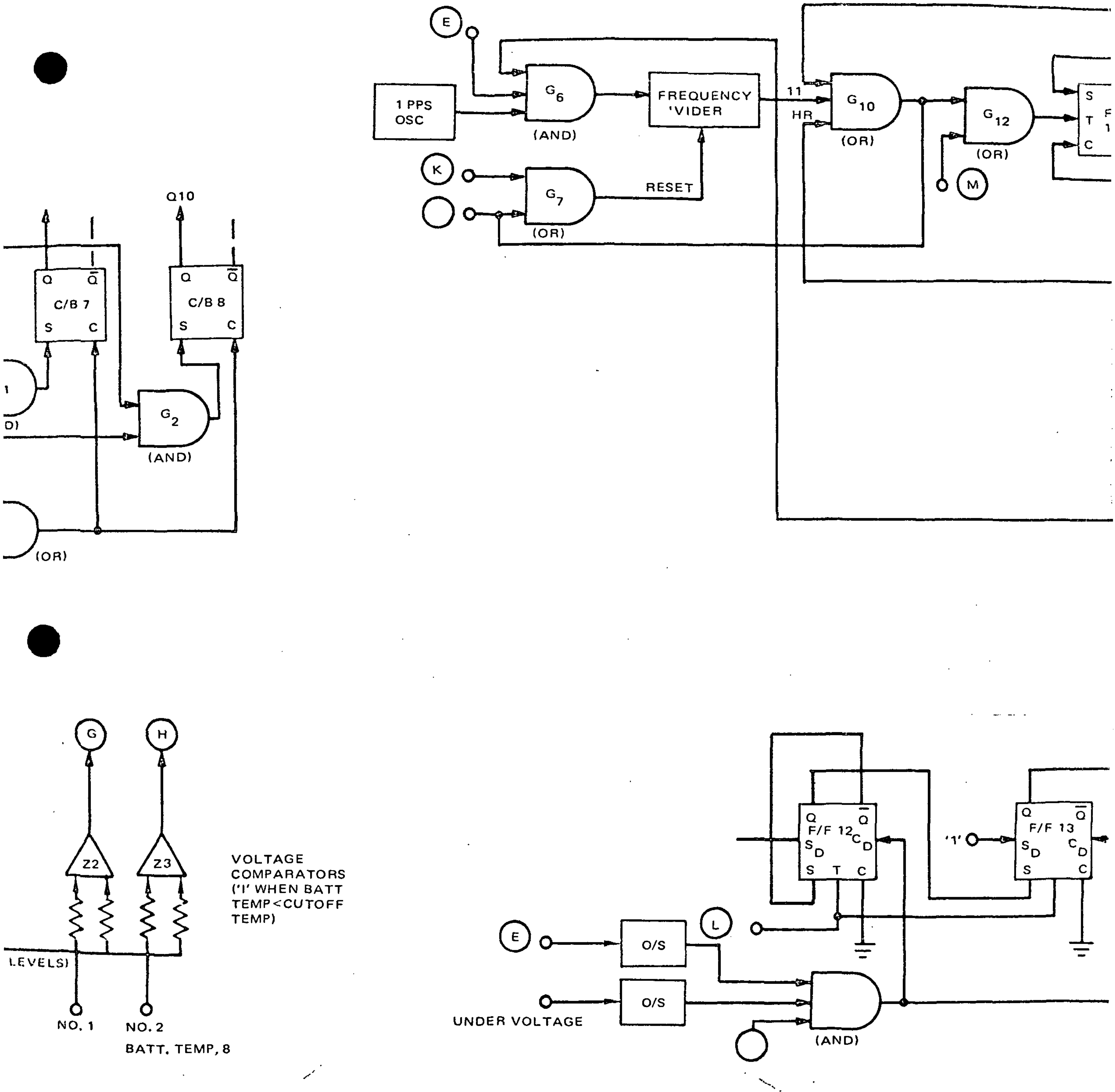


Figure 4-23. Battery Charge Controller Functional Schematic


DISCONNECT CHARGE NO. 1
DISCONNECT CHARGE NO. 2
NORMAL CHARGE
Q2
Q3
Q4
RELAY DRIVER
K_2
RELAY DRIVER
TO DISCHARGE CONTROL
TO DISCHARGE CONTROL
Q10
BATT. NO. 2
Q10
G5
(AND)
Q
$\overline{Q}$
C/B 7
S
C
Q
S
G_1
(AND)
RECOND. BATT. NO. 1
RECOND. BATT. NO. 2
G_2
(AND)
RECOND. DISABLE
(4)
N
(OR)
E
E
Q
$\overline{Q}$
C/B 5
S
B
Q
$\overline{Q}$
C/B 6
S
B
CHG ENAB
CHG DISAB
CK CHG ON
V_{REF}
K5
BUFFER
Z1
(4 LEVELS)
G
H
Z2
Z3
NO. 1
NO. 2
BATT. TEMP.


E
1 PPS
OSC
G6
(AND)
FREQUENCY
'VIDER
11
HR
G10
(OR)
G12
(OR)
S
T
C
M
K
G7
(OR)
RESET
Q10
Q
C/B 7
S
C
C/B 8
G2
(AND)
(OR)
G
H
Z2
Z3
VOLTAGE
COMPARATORS
('I' WHEN BATT
TEMP<CUTOFF
TEMP)
LEVELS)
NO. 1
NO. 2
BATT. TEMP, 8
F/F 12
F/F 13
'1'
L
O/S
UNDER VOLTAGE
(AND)

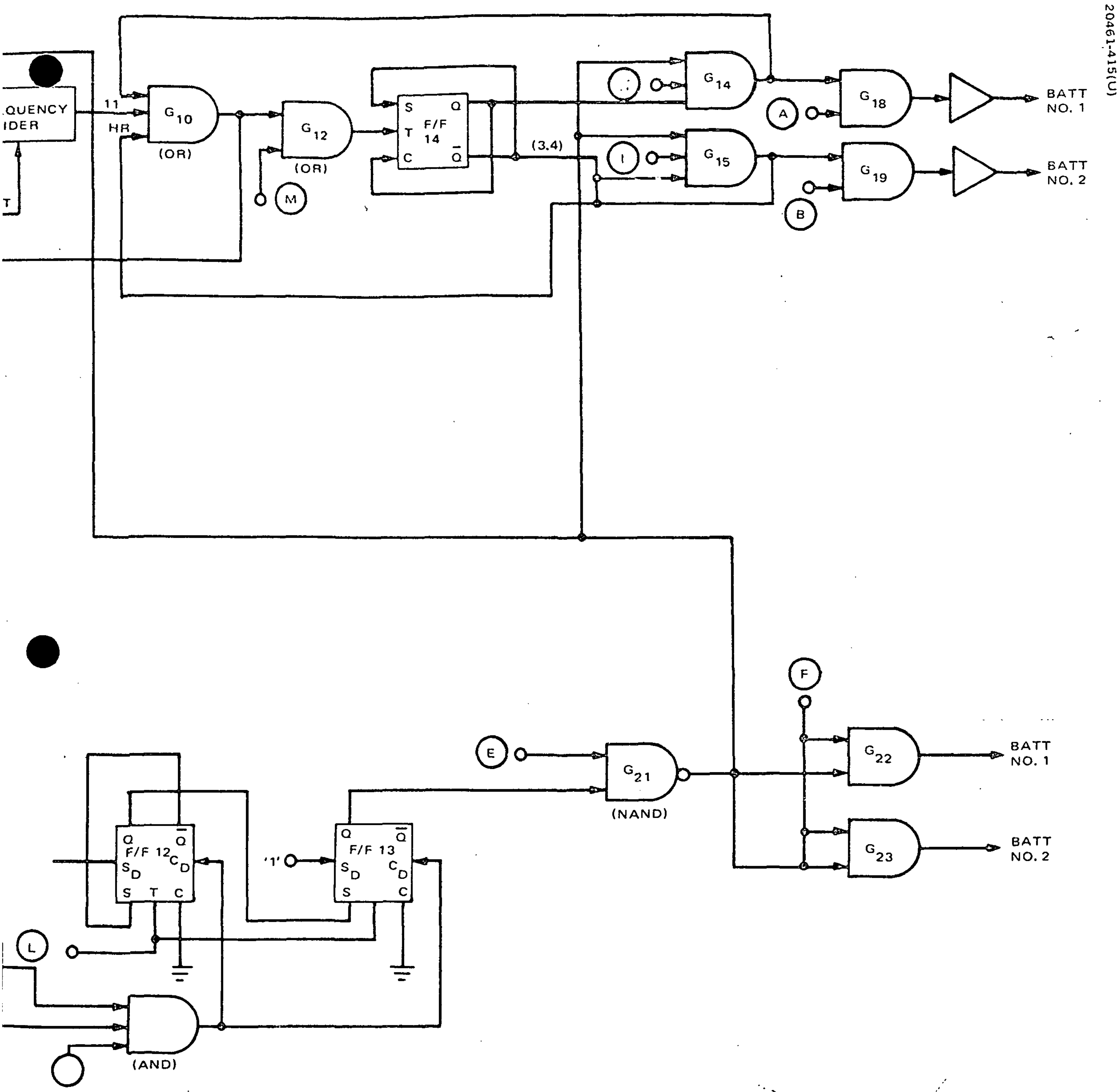

20461-415(U)
QUENCY
IDER
11
HR
G10
(OR)
G12
(OR)
M
S
T
C
Q
F/F
14
(3,4)
G14
G15
A
B
G18
G19
BATT
NO. 1
BATT
NO. 2
F
E
G21
(NAND)
G22
G23
BATT
NO. 1
BATT
NO. 2
F/F 12
F/F 13
'1'
L
(AND)

TABLE 4-27. SOLAR ARRAY DESIGN

Number of panels:	1
Size	
Diameter	2.16 meters
Length	2.21 meters
Mass	20 kg, excluding substrate
Solar cells	2 x 2 cm 0.18 mm, (7.2 mil) thick
Base resistivity	10 ohm-cm
Solar cell cover	0.15 mm (6 mil) thick
Nominal cell voltage (near maximum power)	0.425 volt
Nominal cell current (near maximum power)	0.122 ampere
Temperature	Function of location and season
Radiation degradation	
Current	0.902
Voltage	0.942
Fabrication loss	
Voltage	1.00
Current	0.98
Ripple	0.98
Effective illuminated area in current	0.318
Curvature edge defects, current	0.962
Solar angle	±0.554 radian
Seasonal intensity	
Summer solstice, current	0.888
Autumnal equinox, current	0.993
1.99 Ms (23 days) before autumnal equinox, current	0.969
Transmission loss, current	0.98
Diode drop	0.8
Panel harness drop	0.3 volt

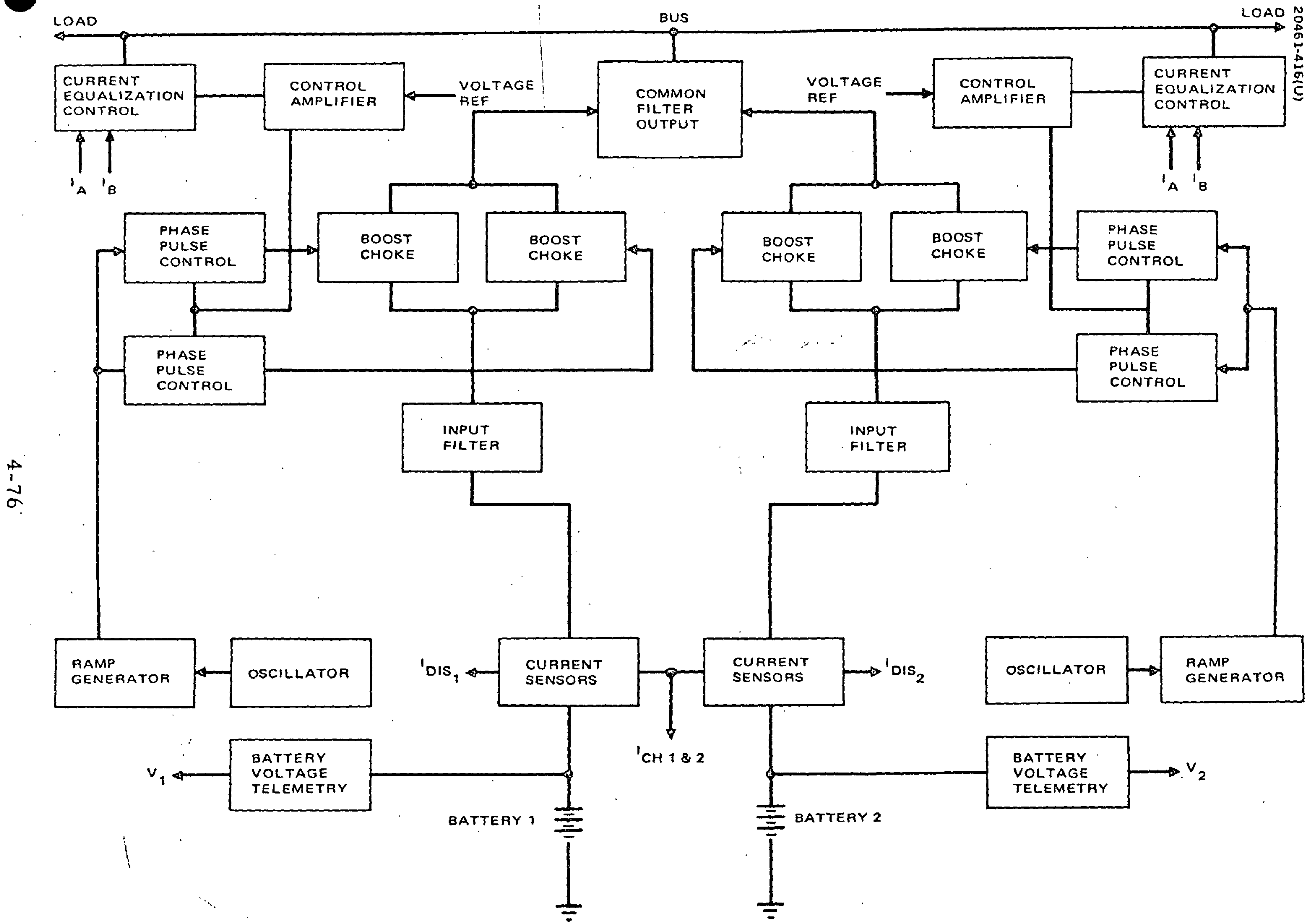


Figure 4-24. Battery Discharge Control Block Diagram

TABLE 4-28. POWER SUBSYSTEM PERFORMANCE

Solar Array Output End of Life	
Summer solstice	364 watts
23 days before equinox	399 watts
Solar array output augmented by batteries	438 watts
Maximum bus voltage	30 volts
Battery discharge turn-on voltage	25. 5 volts
Minimum bus voltage, battery power	24. 5 volts
Solar array maximum power voltage	26. 5 volts
Solar array temperature maximum 300 K, minimum 183 K	
Battery depth of discharge maximum	60 percent
Number of eclipse cycles	450
Solar array augmentation maximum	4. 5 percent
Maximum augmentation cycles	7000
Battery charging rate	C/15
Battery charge termination	Temperature signal
Battery trickle charge rate	C/60
Cell failures permitted per battery	2
Battery discharge voltage	24. 3 to 17. 5 volts
Battery operating temperature range	225 to 300 K
Battery discharge controller voltage	25. to 26. 5 volts
Battery charge controller operation	Automatic or ground commanded
Battery discharge controller operation	Automatic
Battery reconditioning	On ground command
Tap limiters; operating voltage	29 to 29. 5 volts
Bus limiters; operating voltage	29. 5 to 30 volts

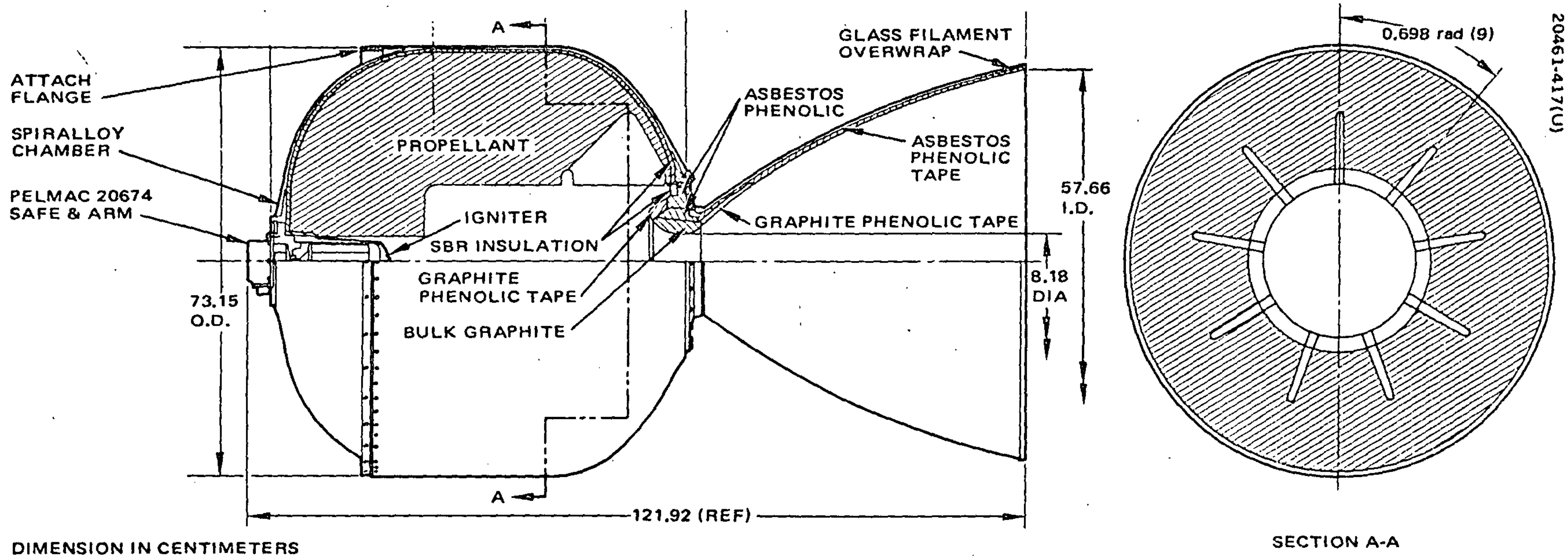


Figure 4-25. Apogee Kick Motor

lightweight design and utilize a high performance propellant in order to achieve an efficient payload/spacecraft mass ratio. The nominal velocity increment of 1679 m/sec is required for the TDR spacecraft mass of 678 kg at boost vehicle separation.

The Hercules Incorporated motor design (Figure 4-25) with a propellant of 302.2 seconds effective ISP, is used for the TDRS. The TDRS apogee motor characteristics are listed in Table 4-29. The motor case is of S-glass reinforced plastic. The pressure chamber interior is thermally protected from the combustion gases by styrene-butadiene rubber insulation. The nozzle throat and inside exit diameters are 8.19 and 57.7 cm, respectively. Internal surfaces are fully contoured, and efficiency losses and erosion are minimized by a hyperbolic spiral entry. The expansion cone is contoured to a basic Rao parabolic geometry, modified for the propellant metal content, and provides an expansion ratio of 50:1.

The entrance and throat region is supported with an aluminum attach flange. The expansion cone is a composite of graphite phenolic from the throat insert aft to an expansion ratio of 7:1, and asbestos phenolic extends

TABLE 4-29. APOGEE MOTOR REQUIREMENTS

Performance	
ΔV	1679 m/sec ±1% (5498 fps ±1%)
Maximum thrust	9000 lb
Maximum acceleration	113 m/sec^2 (11.5 g)
Maximum external case temperature	333 K (500°F)
Physical	
CG: Loaded	0.046 cm (0.018 in.)
burned out	0.102 cm (0.040 in.)
Balance: loaded	0.22 kg-m^2 (1200 oz in^2)
burned out	0.11 kg-m^2 (600 oz in^2)
Thrust alignment displacement	0.051 cm (0.020 In.)
angular	0.002 radians (0.002 in/in)
Moment of inertia	Known within ±5%
Environmental	
Operating temperatures	278 to 306 K (40 to 90°F)
Storage life	3 years
Spin rate	10.47 rad/sec (100 rpm)
Hard vacuum	10 days

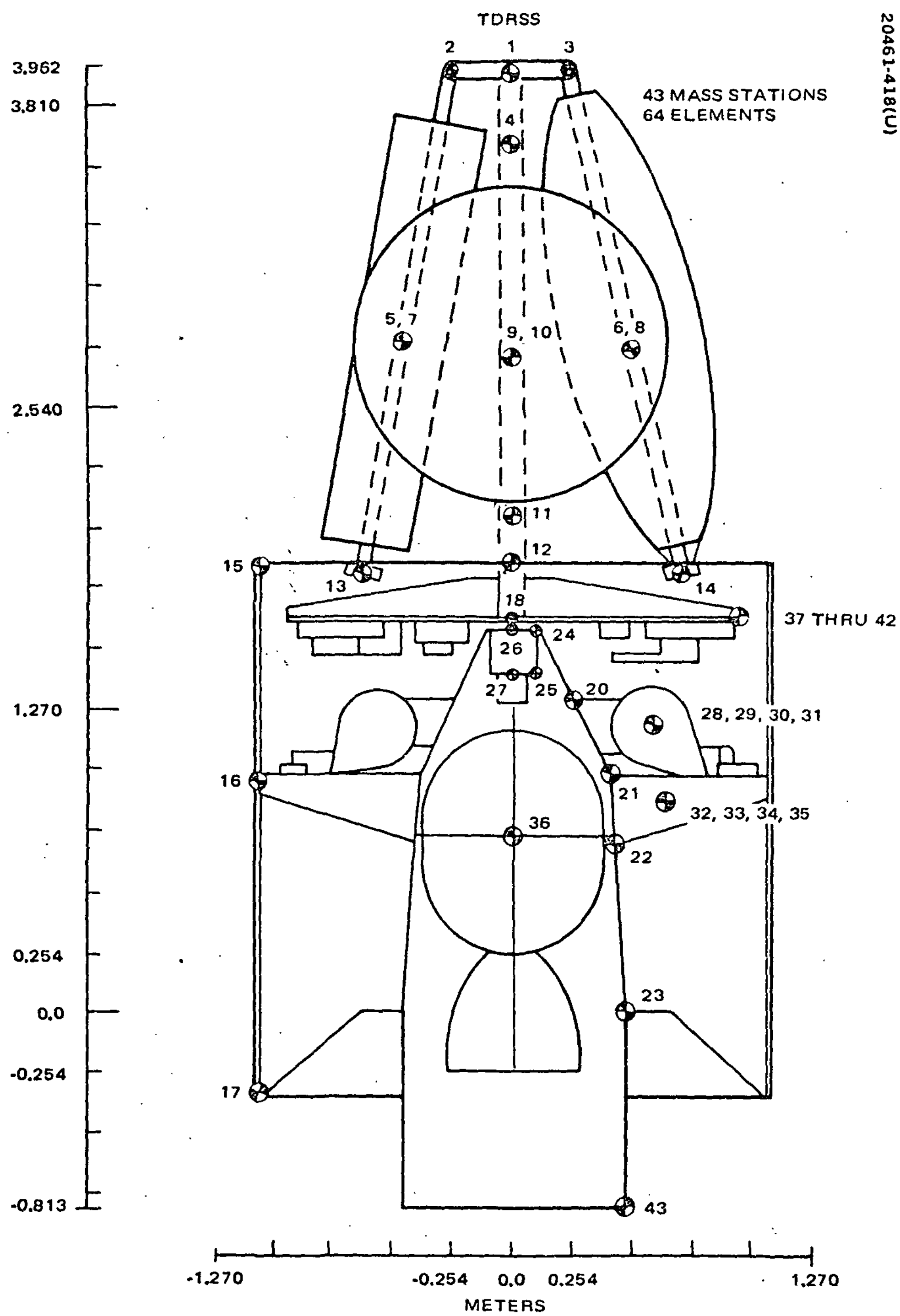


Figure 4-26. Structure Model and Mass Stations

through the rest of the cone. The entire structure is overwrapped with glass filament. The propellant is a composite-modified double base formulation of proven high specific impulse, high density, and excellent mechanical properties. The propellant grain configuration consists of a centerbore with nine aft-end wing slots, a configuration that achieves a relatively constant thrust during motor burn.

The motor ignition system consists of the Pelmac 20674 electromechanical safe and arm device, located at the forward end of the motor, and a pyrogen igniter mounted to the forward closure.

Motor performance data are listed in Table 4-30 for a nominal operating temperature of 297K (75°F) along with motor mass properties. A total motor weight of 318 kg is predicted for the TDRS application.

4.3.8 Spacecraft Structure

The spacecraft structure subsystem functions as the integrating platform for all mission specific payload elements and subsystems during ground handling, launch, and orbital flight. The structure must be designed to sustain the mechanical, thermal, and radiation environments during the TDRS 7 year mission life, including prelaunch, ground handling without failure or excessive deformation. The physical dimensions of the TDRS structure must be compatible with the Delta 2914 launch vehicle and its standard 3731 spacecraft adapter.

The TDR spacecraft structure subsystem is illustrated in Figure 4-26. The primary load carrying structure is divided into a spun section, despun equipment platform, and an antenna support mast.

TABLE 4-30. APOGEE MOTOR PERFORMANCE AND MASS

Parameter	Nominal Value
Vacuum specific impulse	302.2 sec
Vacuum total impulse	193,700 lbf-sec
Average vacuum thrust	4230.18 kg (9440 lbf)
Average chamber pressure	621 psia
Burn time	21.2 sec
Propellant mass	290.30 kg (640 lbf)
Total motor mass	317.97 kg (701 lbf)
Burnout mass	25.40 kg (56 lbf)

The spun section consists of a thrust cone and four equipment carrying ribs. A thin magnesium plate connects these ribs for added shear rigidity. The cylindrical solar panel substrate is attached to the ribs.

The despun structure consists of the circular equipment shelf of honeycomb sandwich construction and radial rib reinforcement. A tubular mast, mounted centrally forward of the despun platform, provides antenna support. The structural interface between spin and despun section is achieved by a precision bearing assembly (BAPTA). This bearing is excluded from the primary load pass by use of a Marman type clamp during the spacecraft launch periods of high structure loading.

Types of construction for major structural components and their materials are shown in Table 4-31. The dynamic characteristics of the spacecraft in launch configuration have been computed. Results of this analysis (Table 4-32) indicate a structure of sufficient rigidity; e.g., no axial resonance is predicted at Delta pogo frequency of about 20 Hz.

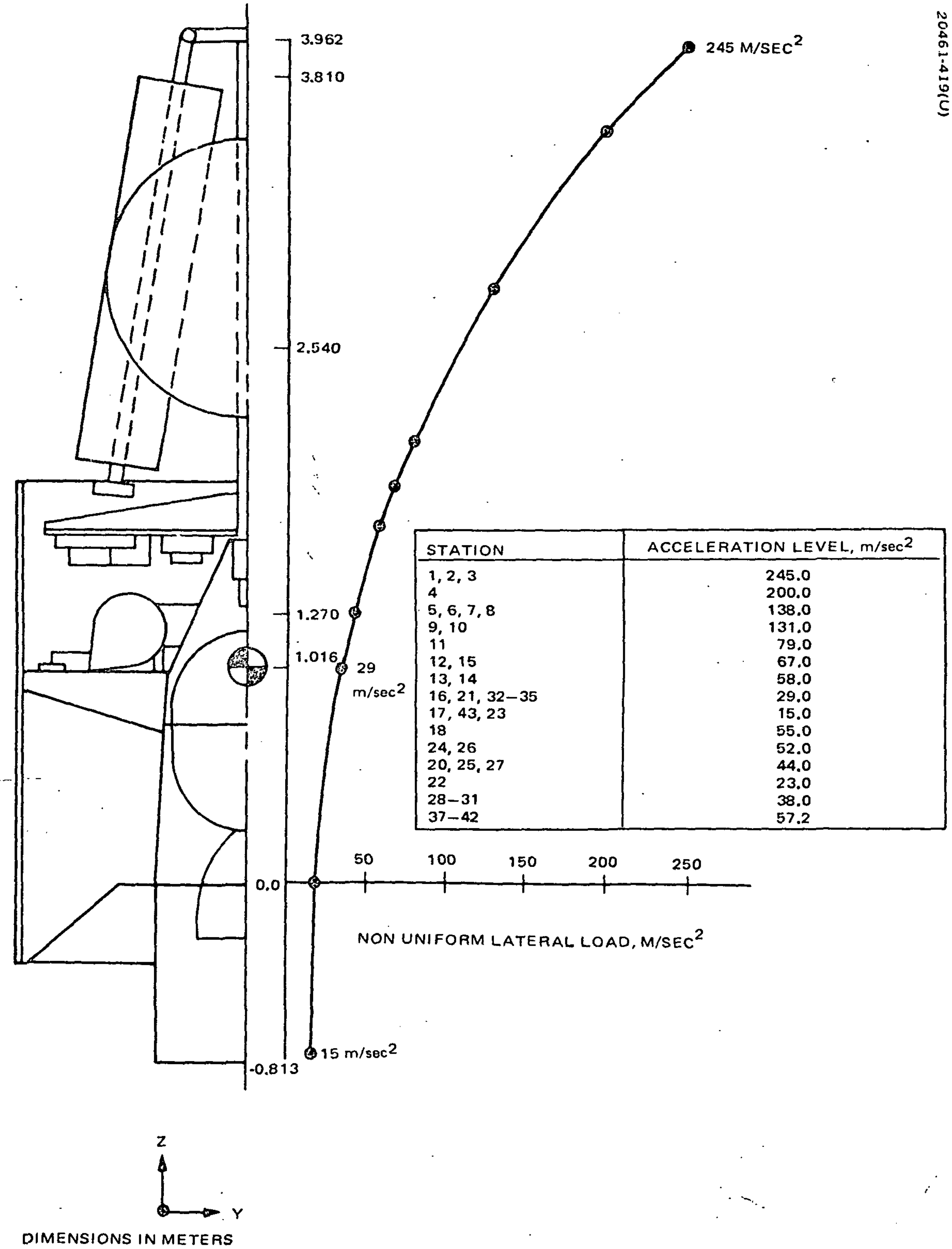
The primary structure has been analyzed for quasi-static loading conditions, the most severe one of which proved to be the nonuniform lateral loading case shown in Figure 4-27. Positive strength margins were demonstrated for all structural elements.

TABLE 4-31. PRIMARY SPACECRAFT STRUCTURE

Item	Type of Construction	Material
Central thrust tube	• Monocoque cylinder with end rings	• Beryllium, aluminum
Spun platform	• 4 ribs • Monocoque shelf (20 mils) with edge stiffeners	• Beryllium • Magnesium
Cylinder solar substrate (85 in. diameter, 87 in. length)	• Honeycomb core (3/4 in.) • 2 ply facesheets	• Aluminum • Fiberglass
Despun platform	• Honeycomb core (1/2 in.) • Facesheets (10 mils) • 6 ribs	Aluminum Aluminum Beryllium
Antenna support mast	• Monocoque tubes 5 in. diameter tapered thickness (45 to 90 mils)	• Beryllium

TABLE 4-32. MODAL CHARACTERISTICS

Mode	Frequency, cps	Type
1	11.2	X bending of mast
2	12.3	First despun torsion
3	13.6	Y bending of mast
4	23.1	Second Y bending
5	24.4	Second Y bending
6	26.1	First despun shelf rocking (Y axis)
7	36.8	Second despun shelf rocking (X axis)
8	38.2	First solar panel torsion
9	41.1	Third despun shelf mode (X axis) antenna coupling
10	43.9	Antenna mode (X)
11	44.8	Fourth despun shelf rocking (Y axis)
12	44.9	Antenna mode (Y)
13	46.0	Fifth despun shelf plate mode (about X axis) (antenna coupling)
14	46.1	Sixth despun shelf plate mode
15	46.4	Antenna (X)
16	46.7	Antenna (Y)
17	53.7	Antenna, despun shelf coupled
18	55.3	K_u band parabolic reflect antenna
19	56.2	Antenna, despun shelf coupled
20	59.0	Solar panel X bending
21	59.1	Solar panel Y bending
22	72.4	Antenna mode
23	85.0	Third X bending
24	89.6	Tank mode
25	90.0	Coupled X bending (fourth) and tank mode
26	90.7	Tank mode
27	91.1	Coupled X bending (fourth) tank and apogee motor
28	92.8	Tank mode
39	149	Axial of solar panel
48	223	Axial of solar panel



STATION	ACCELERATION LEVEL, m/sec^2
1, 2, 3	245.0
4	200.0
5, 6, 7, 8	138.0
9, 10	131.0
11	79.0
12, 15	67.0
13, 14	58.0
16, 21, 32–35	29.0
17, 43, 23	15.0
18	55.0
24, 26	52.0
20, 25, 27	44.0
22	23.0
28–31	38.0
37–42	57.2

Figure 4-27. TDRSS Design Loads - Condition 2: Lateral Loads

4.3.9 Thermal Control

The temperature environment for all satellite subsystems during the mission life of 5 years is controlled by the thermal design and thermal control. The orbital design must be compatible with survival and/or operation of all subsystems during ascent, transfer to synchronous orbit, apogee motor burn, and on-orbit operations. Table 4-33 presents the subsystem temperature requirements that have been established for the TDRS. Table 4-34 outlines the expected extremes in system power dissipation using baseline estimates of equipment power requirements, operational modes, and solar panel electrical characteristics.

The thermal control concept employed in the TDRS design is one of passive thermal control, which takes advantage of both the temperature averaging that results from the uniform spin rate of the vehicle solar panel and the containment of the sun within ±0.41 radian of the orbit plane. The key features of the thermal design are identified in Figure 4-28. Radiation is the dominant mode of heat transfer between major spacecraft elements. The temperatures of the spinning structure and low power dissipation regions are controlled by providing good radiation coupling to the solar panel. The batteries are hard mounted to the structural ribs in order to provide thermal fin capability. The lines and valves of both the axial and radial thrusters are provided with molded blanket heaters (a heater system of 0.03 watt/meter propellant line and 0.75 watt per thruster is used) that prevent any portion of the system from reaching the freezing point of hydrazine at any time during the operational life of the spacecraft. These heater elements are wrapped with low emittance aluminum tape to minimize the heater power requirements. The hydrazine tanks are maintained above the freezing point with multilayer insulation.

Most of the power dissipating units are grouped on a despun platform across the forward end of the solar panel. Platform dissipation is radiated to an intermediate radiating surface provided just forward of the platform. Most of the intermediate radiating area (inboard) is despun, while the outermost rim is spinning. The high dissipating units are located near the perimeter of the despun shelf, below the spinning cover. A second surface aluminized teflon finish on the intermediate surface serves to attenuate the temperature variation of the platform with respect to solar incidence angle. Temperature sensitivity of this platform is further attenuated by radiation coupling to the stable solar panel boundary.

The antenna mast is treated with a combination of aluminum foil and second surface aluminized teflon stripes in order to limit both the thermal bending of the mast and the peak temperature of the cabling that will be attached to the mast. The mast is insulated for approximately 0.9 meter above the sunshield to provide the desired boundary conditions for the motor bearing assembly. The antenna element will have high emittance finishes only to the extent necessary to limit peak temperatures below 422 K in any critical areas.

TABLE 4-33. SUBSYSTEM TEMPERATURE REQUIREMENTS

Equipment	Design Range, K	Eclipse Minimum, K	Comments
Despun			
Transmitters, receivers and other repeater electronics	267 to 311	261	Design limits used in the successful qualification and flight application of similar communication electronics equipment
Telemetry and command electronics	267 to 311	261	
S band antenna positioner	222 to 367	222	Identical to Intelsat IV design limits
Antenna mast and cabling	200 to 367 Mast deflection due to diametral temperature difference < 0.28	200	Similar to TACSAT design
VHF and S band antenna	117 to 395	117	Similar to TACSAT design
Spinning			
Apogee motor	278 to 306	278	Comsat UTC motor design limits
Despin bearing	273 to 311	284	
Despin electronics	267 to 323	261	Intelsat IV
Batteries	273 to 300	273	No overcharge
Solar panel	222 to 297	172	
RCS tanks	278 to 333	278	Intelsat IV design with active heating of lines and valves
lines	278 to 367	278	
valves	278 to 339	278	

TABLE 4-34. THERMAL DISSIPATION LEVEL, WATTS

Equipment	Solar Power 26.5 V		Solar and Battery 25 V	Battery Power 25 V		
	Operating Time					
	75	25	25	75	25	25
Despun						
Data transmitter, K_u band	19.0	19.0	17.9	17.9	17.9	17.9
Command transmitter, S band	11.3	62.8	10.4	10.4	59.0	10.4
Command transmitter, UHF	75.0	75.0	75.0	75.0	75.0	75.0
Voice transmitter, UHF	—	—	75.0	—	—	75.0
Command receiver, K_u band	4.7	4.7	4.5	4.5	4.5	4.5
Data receiver, S band	1.9	1.9	1.8	1.8	1.8	1.8
Data receiver, VHF	1.7	1.7	1.6	1.6	1.6	1.6
Frequency generator	8.1	8.1	7.6	7.6	7.6	7.6
Miscellaneous repeater equipment	9.5	9.5	8.9	8.9	8.9	8.9
Command decoders	4.9	4.9	4.7	4.7	4.7	4.7
Telemetry encoders	10.1	10.1	9.5	9.5	9.5	9.5
Antenna position control	6.0	6.0	6.0	6.0	6.0	6.0
Total	152.2	203.7	222.9	147.9	195.6	147.9
Spinning						
Telemetry transmitter, VHF	—	—	—	—	—	—
Command receiver, VHF	1.2	1.2	1.1	1.1	1.1	1.1
Despin control electronics	19.0	19.0	17.9	17.9	17.9	17.9
Power electronics	18.0	11.0	39.8	40.0	44.0	50.0
Battery charging	60.0	—	—	—	—	—
Total	98.2	31.2	58.8	59.0	63.0	69.0

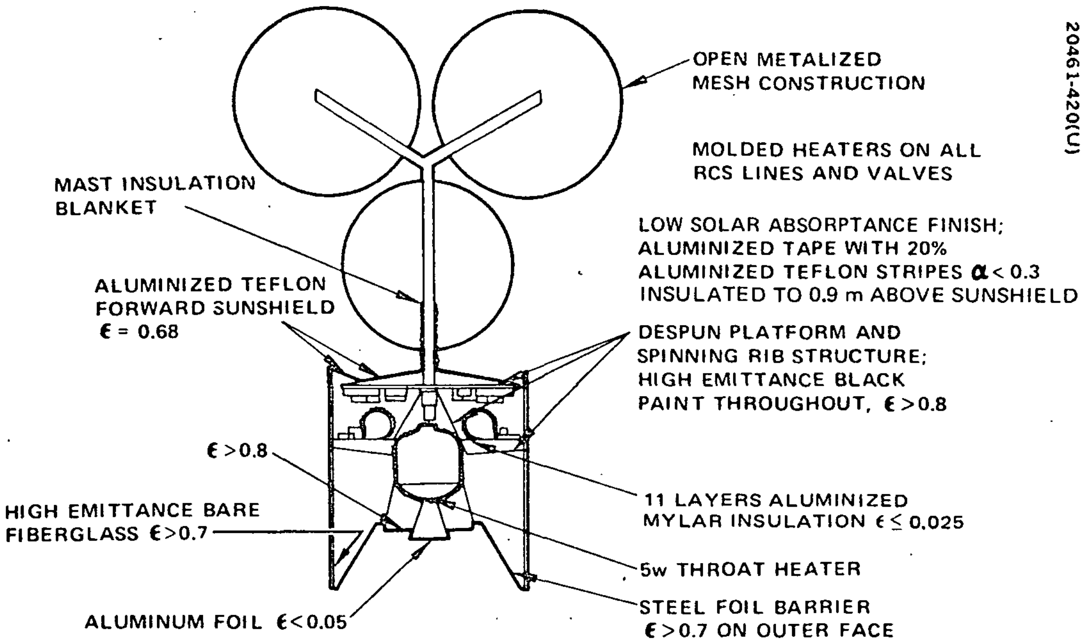


Figure 4-28. Spacecraft Thermal Control Provisions

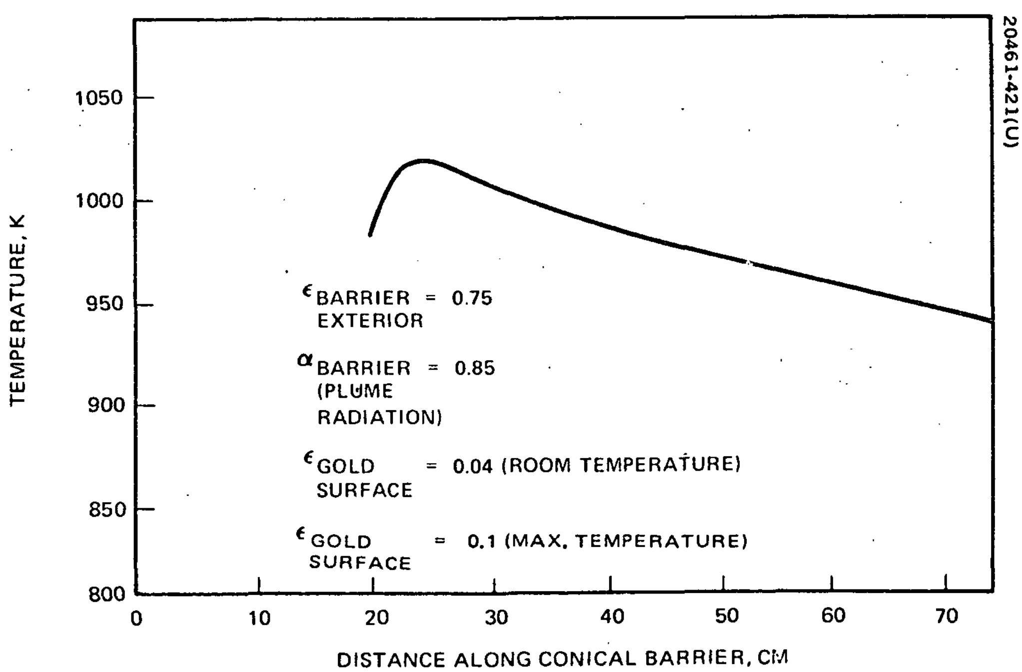


Figure 4-29. Maximum Conical Barrier Temperatures During Apogee Motor Firing

The apogee motor has an aluminized Kapton multilayer insulation blanket to protect the spacecraft from post firing thermal soakback. Additional thermal isolation is provided around the aft end and around and over the nozzle to limit undesirable local temperatures near the nozzle throat during the transfer orbit. In addition to this isolation, an active heater on the nozzle throat is provided to the baseline to assure adequate temperature control of this critical element. The aft end of the spacecraft is closed and protected from apogee motor plume heating by a 0.0051 cm thick stainless steel foil which is thermally isolated at the spacecraft attach points. Its exterior surface is coated with Bo-Chem black oxide. The interior surface is coated with hanovia gold to provide the required thermal isolation. The predicted maximum temperature distribution along the conical barrier is shown in Figure 4-29. Combined heating rates are high, and equilibrium temperatures are reached in about 10 seconds, so that for short periods the allowable temperature of 923K is exceeded.

Adequate thermal control performance has been demonstrated by preliminary analysis. The power temperature performance characteristics of the despun platform design are shown in Figure 4-30. The temperature performance is well within the equipment design range for the extremes in both season and operating mode. Further, the end of life performance of the degraded teflon sun shield appears adequate for this mission. Table 4-35 lists the temperature predictions for both a warm and cold boundary condition of the central bearing assembly.

TABLE 4-35. BAPTA THERMAL PERFORMANCE

Node	Location	Minimum Steady State Boundary, K	Maximum Steady State Boundary, K
1	Upper inner bearing race	280	304
2	Upper outer bearing race	281	305
3	Upper despun flange	281	304.5
4	Center outer spinning housing	282	304.5
5	Lower spinning flange	280.5	304
6	Lower outer bearing race	291	308
7	Lower inner bearing race	291.5	307.5
8	Lower despun flange	291.5	307.5
9	Center despun shield	284	306
10	Spinning cone structure	279	301
11	Slip ring assembly	291.5	307.5

The temperature differential across the bearings is less than 2.8K for the worst case conditions. A 3 watt dissipation in the slip ring assembly will cause that section to run about 8.3K warmer than the motor housing; however, it will remain well below the 323K allowable temperature for the slip ring assembly. All motor and bearing temperatures will remain within the 273 to 311K operational design range.

The steady state solar panel temperature will vary from a minimum of 285K at summer solstice to a maximum of 295K at equinox. The battery system can constitute the major thermal dissipator on the spinning side of the spacecraft. The effective environmental sink temperature will range from 278 to 295K.

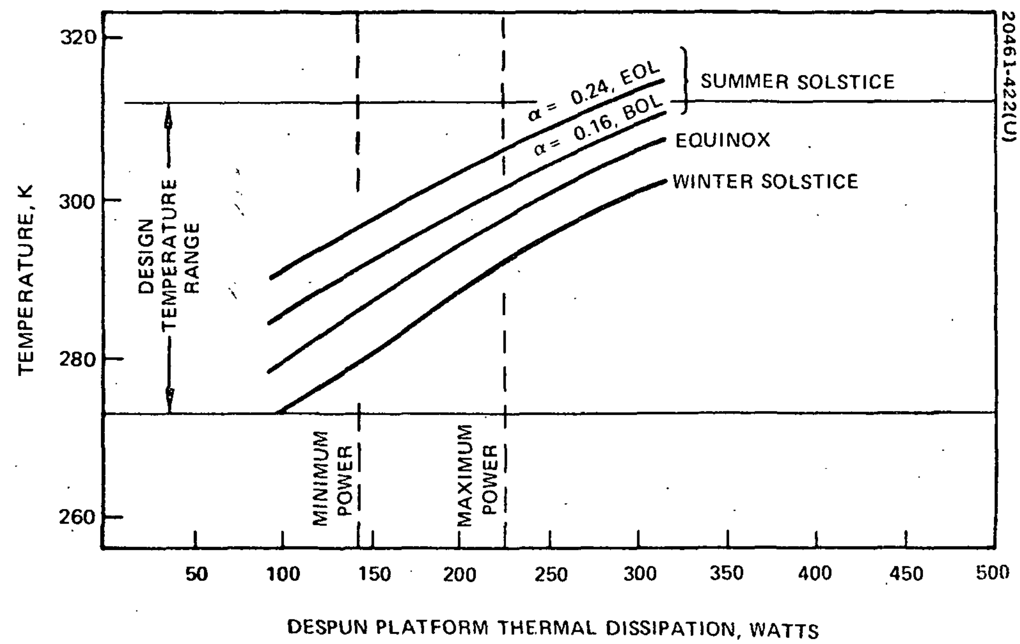


Figure 4-30. Despun Platform Power Temperature Performance